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Limnological and Fisheries Evidence
for Rearing Limitation of
Coho Salmon, *Oncorhynchus kisutch*,
Production from Sea Lion Cove Lake,
Northern Southeast Alaska (1980-1983)
R. A. Crone, Ph.D. *
and
J. P. Koenings, Ph.D.
Number 54

Alaska Department of Fish & Game
Division of Fisheries Rehabilitation,
Enhancement and Development

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PART I: SEA LION COVE FISHERIES PROGRAM

by

R. A. Crone

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(Part I)

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ABSTRACT

In order to apply the most efficient coho salmon, *Oncorhynchus kisutch*, enhancement strategy at Sea Lion Cove Lake, an assessment was made of the fisheries and limnological conditions that determine successful rearing of coho fry to smolt. We have utilized a two-tier approach that specifically addresses fishery ecology (Part I) as one tier and limnetic production patterns (Part II) as the second.

Sea Lion Cove Lake is inaccessible to anadromous adult salmon because of a natural barrier to upstream migration. However, successful downstream migration (by smolts) is possible, suggesting the use of the lake as a fry rearing site. In 1982 coho fry were stocked into the lake at a density of 2020 fry/ha. The fry grew rapidly (>1.0 mm/d) on a diet of large body sized calanoid and cladoceran zooplankters. Even though a later reduction in the number of larger (>1.1 mm) diaptomids was accompanied by a slower fry growth rate (0.4 mm/d), 78% of the added fry emigrated in the spring of 1983 as large (mean length 114 mm and mean weight 13.5 g) age-1.0 smolt.

The lake is very shallow, having a mean depth of 4.3 m, and is heavily influenced by climatic conditions related to a short-water residence time of only 0.25 y. However, a stable epilimnion formed in the first part of June and persisted until the end of September, with surface temperatures exceeding 16°C for short periods. As a consequence of warm temperatures, high winds, and a large littoral shelf area, total phosphorus levels doubled during the summer period, rising from 4 μg L^{-1} in the spring and reaching 8 μg L^{-1} by the fall. Throughout the summer period, the euphotic zone extended deeper than the thermocline and allowed for the formation of hypolimnetic plates of phytoplankton. As hypolim-

netic chl $\underline{a}$ levels often exceeded those within the epilimnion; such deep layers of phytoplankton avoid both the periodic washout and the lowered inorganic nitrogen levels associated with the epilimnion.

Finally, although the smaller body sized *Bosmina* and *Cyclops* (0.32 to 0.96 mm) numerically dominated the zooplankton community, the larger body-sized *Diaptomus* and *Epischura* (0.62 to 2.15 mm) were important forage items for rearing coho fry. Although coho fry actively foraged on the larger zooplankters, the seasonal density patterns and seasonal mean body size of the calanoids were seemingly unaffected by the initial fry stocking. However, as coho fry are faculative planktivores, the proper density and body size of zooplankters preferred by the coho were critical for the successful production of age-1.0 smolt.

Key Words: Coho salmon, *Oncorhynchus Kisutch*, Sea Lion Cove, rearing fry, smolt, smolt production, stocking density, primary forage, zooplankton forage, size selection, fry growth rates.

INTRODUCTION

In recent years, lakes lying above barrier waterfalls and con-
taining abundant invertebrate populations have been studied by the
Alaska Department of Fish and Game (ADF&G), National Marine
Fisheries Service (NMFS), Northern Southeast Regional Aquaculture
Association (NSRAA), USDA Forest Service (USFS), and other agen-
cies as an alternative to standard, feed-lot-rearing hatcheries
for raising salmon fry to smolts. Results have been varied, but
the overall indication is that the technique may be an important
method of enhancement for some salmon species, particularly coho,
Oncorhynchus kisutch.

The use of barriered lakes for producing smolts does not eliminate
the need for hatcheries to incubate the eggs and care for the
alevins and fry. Other costs include transportation of the fry to
the lake, monitoring of their performance in the lake, and
evaluation of the lake's invertebrate populations after these
salmon fry have been stocked. Some of these costs remain constant,
regardless of lake size, and as a result, large barriered lakes
(400 ha and larger) are the least costly (per smolt produced) to
use for rearing juvenile salmon. However, only a few large lakes
are available in southeastern Alaska for salmon stocking.
Consequently, NSRAA has developed its barriered-lake coho rearing
program around the use of smaller lakes lying in close proximity
to each other (i.e., clusters of lakes). A total of 400 to 600 ha
of lake surface area per cluster is deemed necessary to produce
enough smolts to be cost effective. One method of increasing the
cost effectiveness of the barriered-lake rearing technique would
be to increase the smolt yield obtained from the small lakes so
that fewer would be required to produce the desired number of
smolts and adults. Nutrients have been added to nonbarriered,
sockeye salmon, *O. nerka*, nursery lakes in Alaska and British Columbia
as well as to coho nursery lakes in Alaska to increase the amount
of food available for presmolts and, thereby, to enhance the quantity

and quality of the smolts produced (Nelson and Edmondson 1955; LeBrasseur et al. 1978; Kyle and Koenings 1983). Similarly, fertilization should result in increased invertebrate prey abundance in barriered lakes, allowing many more salmon fry per lake to be stocked while maintaining good growth and survival. Thus, a substantially increased smolt yield per lake would reduce the number of lakes necessary to produce the desired number of smolts.

Study Site Description

The site for the proposed study is a small, unnamed lake located near the northern end of Kruzof Island (57°18.3'N, 135°47.1'W) in southeastern Alaska (Figure 1). The outlet stream from this lake (ADF&G stream no. 113-61-005) flows west and enters salt water at Sea Lion Cove. For convenience, the lake has recently been referred to as Sea Lion Cove Lake, and that name will be used for the remainder of this discussion. A 47-m-high waterfall, 1.1 km above tidewater and 0.3 km downstream from the lake, prevents fish access to the lake. Geologically recent glaciation removed any fish that historically might have been present in the lake. There is no record of fish introductions having been made in Sea Lion Cove Lake prior to the 1982 stocking of coho fry discussed below.

Sea Lion Cove Lake lies at an elevation of 67 m and has a surface area of 7.5 ha (18.6 acres). Maximal depth is 11.5 m; mean depth, 4.3 m. The lake has an extensive shoal area around much of its perimeter and more than half (58%) of the lake surface lies over water less than 5 m deep (Figure 2). A relatively small lake volume coupled with an annual watershed precipitation of some 400 cm results in a theoretical water residence time of just three months.

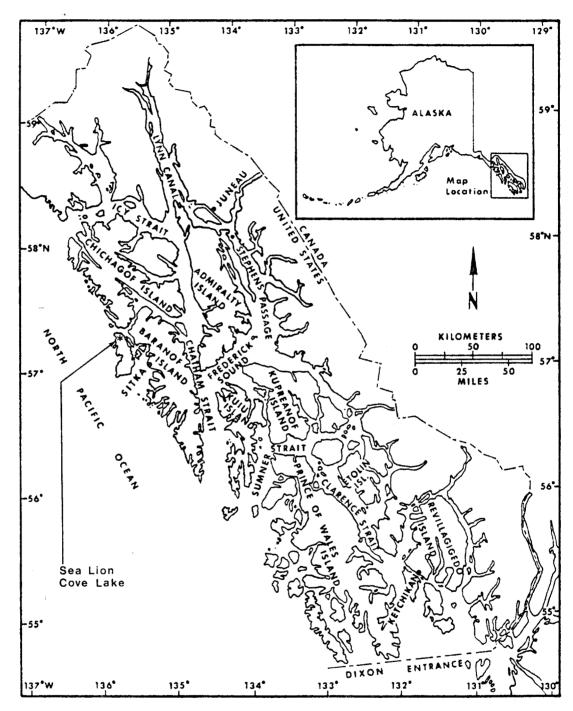Figure 1. Southeastern Alaska and the location of Sea
Lion Cove Lake, site of the proposed study.
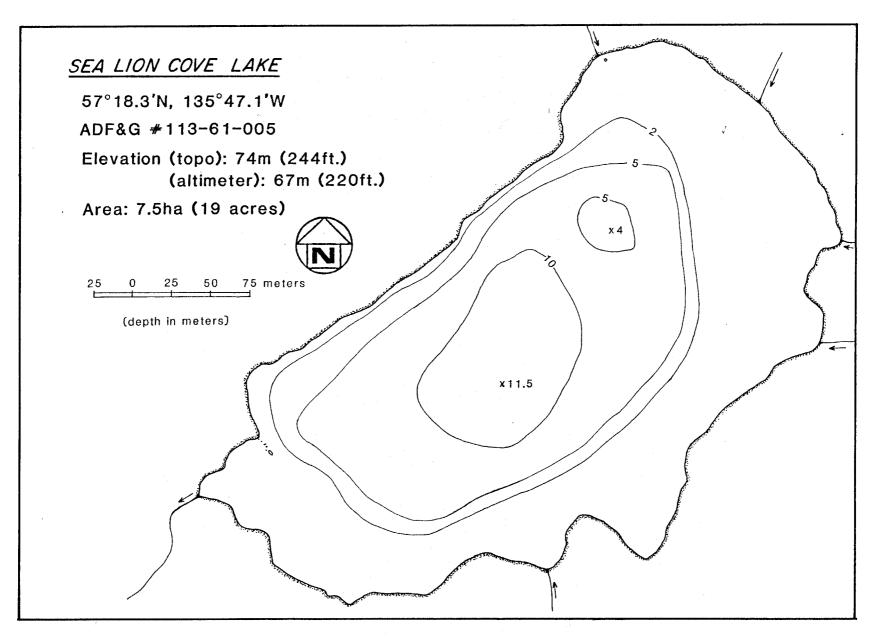
SEA LION COVE LAKE

57°18.3'N, 135°47.1'W

ADF&G #113-61-005

Elevation (topo): 74m (244ft.)
(altimeter): 67m (220ft.)

Area: 7.5ha (19 acres)

25 0 25 50 75 meters

(depth in meters)

Figure 2. Bathymetric map of Sea Lion Cove Lake.

METHODS AND RESULTS

Coho Fry Stocking Program

On 8 July 1982 NSRAA stocked coho salmon fry in Sea Lion Cove Lake
as part of a cooperative salmon enhancement project with ADF&G and
USFS. The fry were obtained as eggs in the fall of 1981 from
wild-stock coho that entered the two Sea Lion Cove spawning
streams (ADF&G stream nos. 113-61-005 and 113-61-006). A total of
15,150 fry was planted in the lake, yielding an initial rearing
density of 2,020 fry/ha (800/acre). Mean size at stocking was a
52-mm fork length and a 1.4-g individual weight.

In-Lake Fry Growth and Forage Preferences

The planted coho grew very rapidly during the first 4 weeks of
lake residence: an average of 1.1 mm and 5.3% body-weight gain per
day (Table 1). Calanoid copepods were the major prey item during
the period, large cladocerans, chironomids, and other insects were
also eaten frequently. A sample of coho collected 4 weeks later
(8 weeks poststocking) established that growth had slowed to less
than half of the initial rate: 0.4 mm and 1.5% weight gain per day
for the preceding month (August). Stomach-flushing samples taken
in early September indicated that trichopteran larvae and
chironomid pupae had become the major dietary items of the rearing
coho. Gastropods and small cladocerans also were numerous in some
fish stomachs. Midlake, vertical zooplankton tows showed that a
large decrease in the density and mean size of the calanoid
copepods had occurred during August (Table 1). The coho growth
rate slowed even further during September and early October, when
mean size increased only about 5 mm and 1 g for the period.
Gastropods, trichopterans, *Bosmina*, and chironomid larvae were
being consumed most frequently by coho collected in mid-October.
In 1982 the last coho samples for size measurement were collected

Table 1. Seasonal variation in the density and body size of calanoid copepods, food selection by rearing coho, and coho growth in Sea Lion Cove Lake following the stocking of 15,150 coho salmon fry on 8 July 1982.

Sampling date(s)	Time since stocking (weeks)	Calanoid copepods Density (no./m^2)	Mean length (mm)	Abundant prey in coho stomachs	Coho salmon growth Mean fork length (mm)	Mean weight (g)	Interval between samples (days)	Average length change (mm/day)	Percentage weight gain per day (%)
7-9 July	0	19,019	1.8	Calanoid copepods & large cladocerans	52.2	1.4			
							12	1.2	6.8
20 July	2	27,340	1.9	Calanoid copepods, large cladocerans, & various insects	66.9	3.1			
							16	1.0	4.2
3-5 Aug.	4	38,206	1.3	Calanoid copepods, chironomid pupae, & other insects	82.4	6.0			
							27	0.4	1.5
1-2 Sept.	8	8,618	1.1	Trichopterans, chironomid pupae, small cladocerans, & gastropods	92.9	9.0			
							35	0.2	0.4
6-7 Oct.	13	11,038	1.2	- Not determined -	98.4	10.2			
14 Oct.	14	7,005	1.2	Gastropods, trichopterans, Bosmina sp., & chironomid larvae	- Not determined -		33	0.1	0.2
8-9 Nov.	18	4,585	1.2	Gastropods, chironomid larvae, & trichopterans	100.8	11.0			

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in early November. Between mid-October and early November, the
sample means of 101 mm and 11 g represented growth of about 2 mm
and slightly less than 1 g. Coho stomachs flushed on 8 and 9
November contained mostly gastropods, chironomid larvae, and
trichopterans. The daily growth rate during the 4 months of lake
residence ·(between stocking and 8 November) averaged 0.4 mm and
1.7% of body weight.

Although growth rates dropped rapidly after the first month of
lake residence, the juvenile coho continued to gain in length and
weight during the entire 4 months of sampling (Figure 3), and the
population ended the growing season (and therefore entered the
winter) with a high-average coefficient of condition (K=1.07).
Ninety-five percent of the population was estimated to be in the
size range of 84 to 118 mm at the end of the first growing season;
that size is large enough to expect nearly all survivors to
emigrate from the lake as age-1.0 smolts. Usually, young coho
must reach at least 75 to 80 mm in fork length during the first
growing season in order to emigrate the following spring as
age-1.0 smolts.

On 8 October 1982, 649 coho fingerlings were captured, marked by
excising a portion of the upper lobe of the caudal fin, and
released. As they emigrated the following spring, yearling smolts
were sampled to obtain the marked/unmarked ratio necessary to
estimate the number of coho that had been present in the lake 92
days after stocking. Of the 6,585 smolts that were examined
carefully for the upper-lobe caudal fin clip, 310 were found to be
marked, yielding an estimated population size of 13,765 (95%
confidence interval, 12,337-15,399 [Figure 4]). Thus, the esti-
mated mortality rate during the first three months of lake
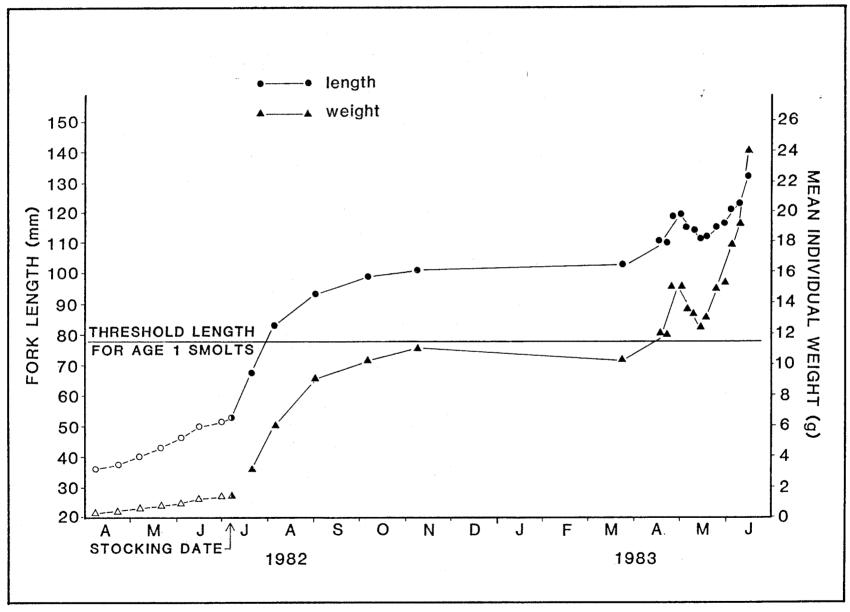residence was only 9.1%.

Figure 3. Estimated fork lengths and weights of the coho salmon population stocked in Sea Lion Cove Lake on 8 July 1982.

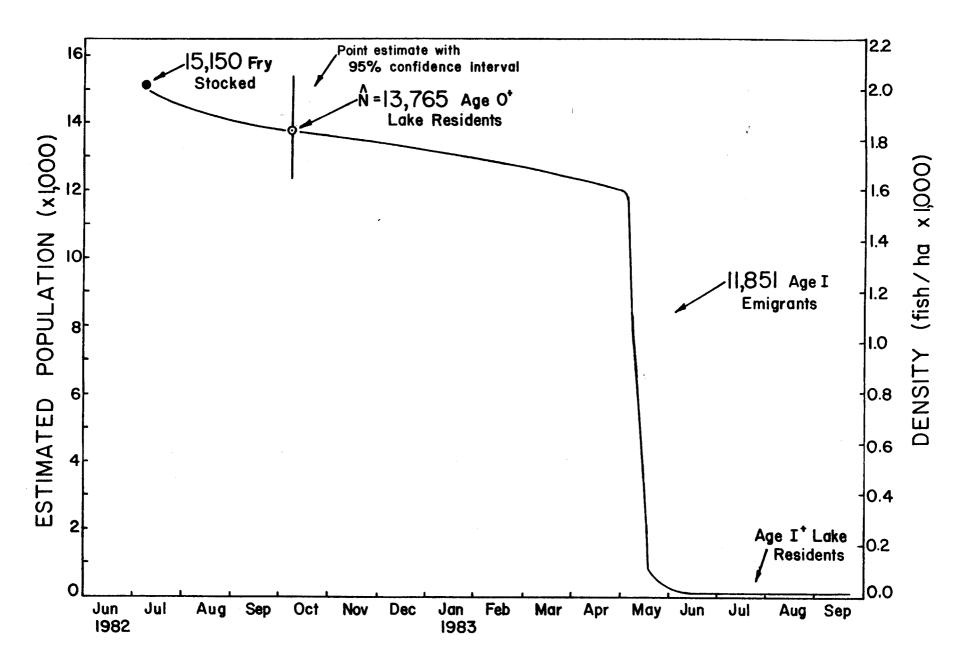# "SEA LION COVE" LAKE COHO SURVIVAL CURVE

Figure 4. Best estimates of the number of juvenile coho salmon remaining in Sea Lion Cove Lake on successsive dates following June 1982 stocking of fry.

Early Spring Presmolt Size and Diet

In March 1983, shortly before the emigration of age-1.0 smolts, a sample of nearly 900 coho collected from Sea Lion Cove Lake averaged 102 mm and 10 g. A slight increase in length but a decrease in weight and mean-condition factor (K=0.96) occurred during the intervening 4½ months of winter. Because of the mild winter and an early melting of lake surface ice, emerging chironomids were abundant in April and early May, and coho began to grow rapidly at that time. *Chironomid pupae* were the most numerous food item in most of the coho that were examined during April and May.

Smolt Enumeration and Population Characteristics

Trapping of emigrant smolts began 17 April 1983 with the installation of an inclined-screen trap that captured all fish leaving the lake. The first three-day catch of 73 smolts averaged 110 mm and 12 g. Sampling with funnel traps (baited with salmon eggs) throughout the lake on 22 April demonstrated that the lake population of coho had also increased in average size to an estimated 109 mm and 12 g. A total of 11,851 smolts (78.2% of the fry stocked) was counted out of Sea Lion Cove Lake between 17 April and 20 June (Figure 4). Over the entire emigration period, smolts averaged 114 mm and 13.5 g, resulting in a mean coefficient of condition of 0.91. Finally, some of the last smolts to leave the lake in early June were 132 mm and 24 g in size.

Yearling smolts that migrated from Sea Lion Cove Lake totalled 160 kg in biomass, or 21.3 kg/ha. The resulting net yield of 18.4 kg/ha was calculated by subtracting the initial weight of the stocked fish (kg/ha) from the final weight of the fish produced (kg/ha).

Few coho remained in the lake for a second growing season. Extensive sampling with baited (salmon eggs) funnel traps and variable-mesh gill nets produced only 18 fish during the summer and fall of 1983. Nevertheless, the emigrant trap will be fished in the

spring of 1984 to collect all age-2.0 smolts that escaped our presmolt collection efforts.

DISCUSSION

Although coho salmon stocked in Sea Lion Cove Lake performed well in terms of survival and smolt yield, the number of yearling smolts produced appears to be near the maximum obtainable from the lake in its natural state.

Juvenile coho stocked in Sea Lion Cove Lake grew rapidly for about 4 weeks. However, young coho are capable of maintaining a fast growth rate in southeastern Alaska barriered lakes for a much longer period and of attaining a greater body size than was observed at Sea Lion Cove Lake. For example, coho fry planted in Osprey Lake in 1975 grew 0.9 mm per day for more than 8 weeks (NMFS, unpublished data); in 1982 young coho stocked in Banner Lake maintained a growth rate averaging 0.8 mm per day for nearly 11 weeks (NSRAA, unpublished data). In all three lakes, calanoid copepods figured prominently in the diet of coho only during the fast-growth period. Once a shift to a diet of mostly insects and/or other zooplankters occurred, the coho growth rate slowed dramatically.

Even though the annual variation in calanoid copepod numbers in Sea Lion Cove Lake has been large during the years studied, which has made interpretation risky, it appears that the presence of rearing coho hastened the decrease in the calanoid population during August (Figure 5). Because the July abundance of calanoid copepods in Sea Lion Cove Lake in 1982 greatly exceeded 1980 and 1981 populations, the coho may have been stocked during a year when the lake had a higher potential for coho production than in some or, perhaps, most other years.

Studies of barriered-lake coho plants have shown that the mean size of coho at the end of the first growing season (or, if the
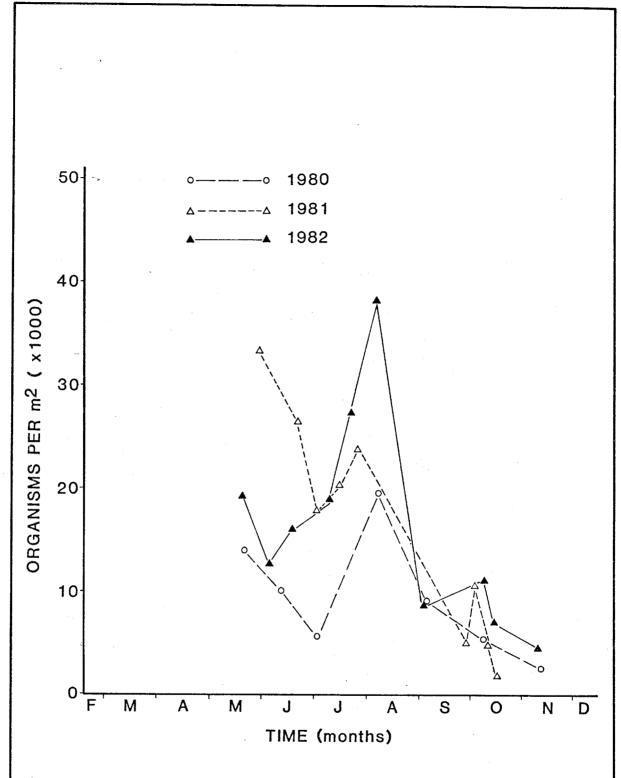
Figure 5. Seasonal variation in the abundance of calanoid
copepods in Sea Lion Cove Lake as estimated from
vertical-tow samples collected at the mid-lake
station, 1980-82.

winter has ·been mild and the early spring growth has occurred, just prior to the following spring emigration period) will determine the fraction of the population that leaves the lake as age-1.0 smolts and the fraction that remains behind for a second growing season. To maximize the smolt yield and the resulting adult return, it is necessary for nearly all stocked coho to leave barriered lakes as age-1.0 smolts. The coho population in Sea Lion Cove Lake, which had a ≅100-mm-mean fork length in the fall and ≅110-mm one by the end of the next April, were apparently just large enough so that almost the entire surviving population emigrated that spring as yearling smolts.

In comparison, coho fry stocked in Ludvik, Tranquil, and Osprey lakes on Baranof Island did not grow as large during the first year of life, and much larger percentages remained in the lake for a second year (NMFS, unpublished data). In Ludvik Lake, coho grew to an average of about 65 mm by mid-October of the first year and did not increase in mean size the following spring. Only about 10% of the estimated surviving population left the lake as age-1.0 smolts; the remaining ≅90% remained behind for a second growing season. Coho fry stocked in Tranquil Lake reached a mean fork length of ≅70 mm by the end of the first summer and then, prior to emigration, grew to ≅85 mm the following spring. About two-thirds of the surviving coho population left Tranquil Lake as yearling smolts, and the other third stayed in the lake for a second year. Subyearling coho attained a much larger mean size (about 100 mm) by the end of the summer in Osprey Lake but exhibited no additional growth before the emigration of spring smolts began. Nearly 90% of the surviving population migrated from Osprey Lake as yearling smolts. Banner Lake coho grew to a mean fork length of 112 mm by the end of October and to about 120 mm by spring, and like coho in Sea Lion Cove Lake, nearly all survivors left as smolts during that first spring following stocking (NSRAA, unpublished data).

Therefore, the stocking of a considerably larger number of coho fry in Sea Lion Cove Lake would not increase the yield of

age-1.0 smolts but, rather, would increase the number of coho requiring two or more years to reach smolt size. The extended freshwater residence time for some fish and its attendant mortality rate would almost certainly lower the total smolt yield from that obtained by stocking the lake at the 1982 density of $\cong 2,000$ fry/ha. Additionally, because of the holdover coho population, the lake probably would not be ready for restocking with progeny from the returning three-year-old (age 1.1) adults (i.e., survivors from the age-1.0 emigrants). Only an increase in the density and the duration of high numbers of large-sized food organisms (notably, calanoid copepods) would allow for the stocking of larger numbers of coho fry in Sea Lion Cove Lake and, accordingly, result in an increased yield of good quality, age-1.0 smolts. An increase in prey abundance that would permit the rearing of more juvenile coho in Sea Lion Cove Lake might be achieved by increasing the concentration of limiting nutrients in the lake water through periodic applications of fertilizer. Conducted properly, enrichment of the lake would result in large increases in the production of planktonic algae, which in turn would raise the populations of calanoid copepods: the prey necessary for extended, rapid growth by juvenile coho salmon.

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PART II: THE SEA LION COVE LIMNOLOGY PROGRAM

by

J. P. Koenings

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INTRODUCTION

The ability of a lake to serve as a nursery area for rearing coho salmon, *Oncorhynchus kisutch*, fry centers on the production of suitable littoral or limnetic forage, which is defined by the quality and quantity of prey preferred by fry. Equally important are the seasonal timing of forage abundance (relative to the developmental stages of the foraging fry) and the overlapping of predator-prey production/utilization areas. Finally, the proximity of both competitors or predators to either the preferred forage items or the targeted fish species influences the quantity of fish produced (smolt biomass).

The initial empirical framework that concerns the ability of coho fry to rear in lakes has been obtained, in large part, from several whole-lake experiments in southeast Alaska (Crone 1981). Crone emphasized that the effectiveness of lake rearing for coho fry needed to be rigorously tested, because coho fry are typically found rearing in streams and/or rivers. In lakes, however, a similar rearing environment occurs within the littoral zone (or the shoreline area that is within the zone of light penetration). Following natural spawning, coho fry successfully rear in a wide variety of lake types.

Throughout Alaska, a great majority of coho fry spend two years rearing in freshwater (either streams or lakes) before emigrating as smolts to salt water. Coho fry are very territorial; that is, the fry establish a feeding area, and they defend it from competitors, including other coho. Thus, the amount of stream or littoral area as well as the food produced within that area limit the number of rearing coho fry produced. Habitat quality (including substrate type, temperature regimes, wave action, and velocity of current) also affects the number of coho smolts produced. In addition, there are the obvious effects of predation and/or competition for space as well as for food.

Our first attempt at defining the factors responsible for limiting coho growth in lakes began by studying fishless lakes; i.e., those inaccessible to returning anadromous adults. The advantage of this study is the absence of the predation and/or competition factors from the growth algorithm. Habitat quantity and quality therefore became the controlling factors, because the number of rearing fry could be controlled by using variable stocking strategies. Stocking success could then be measured by enumerating resultant smolt and by determining such population parameters as age, length, and weight. Thus, using this approach, we could evaluate the effect of lake type (i.e., quantity of rearing area for any given density of planted fry) on the growth and survival of the fry to the smolt stage.

Once the inability of the lake to produce forage items for a given density of coho fry has been established (by means of finding a reduction in growth and/or survival rates of fry to smolt), habitat enhancement that is directed at critical food elements can be used to further coho smolt production. This approach has been used successfully at Bear Lake, Alaska (Kyle and Koenings 1983), where the ability of the lake to rear juvenile coho was enhanced by nutrient additions to the trophogenic zone as part of the lake enrichment program. In analogous fashion, once the ability of Sea Lion Cove Lake to produce suitable forage for rearing coho fry is challenged, an increase in the production of forage items and, therefore, fry-rearing capacity may be achieved through similar nutrient additions. Our purpose is to evaluate the lake in terms of its compatibility to the lake-enrichment guidelines and, thus, for inclusion into the lake-enrichment program.

Study Site Description

Sea Lion Cove Lake (ADF&G No. 113-61-0015) lies at an elevation of 67 m and is located on Kruzof Island in southeast Alaska (*see* Part I). The lake has a surface area of 7.5 ha, or 19 acres; one

main basin is located approximately in the center of the lake
(Figure 1). The maximal depth (11.5 m) of the lake is found in
this center basin; however, the shoreline is dominated by a shelf
lying at a depth of 2 m that surrounds the center basin but is
most pronounced from the northeast to the southeast shores.
Because of the shallow basin configuration, the mean depth is only
4.3 m, and the volume of the lake is 0.323 x 10^{+6} m^3. Finally,
because the yearly area precipitation is extremely high ($\cong$400 cm)
and the lake volume relatively low, annual water-residence time is
estimated to be 0.25 yr.

METHODS

Transportation to and from Sea Lion Cove was provided by float-
equipped aircraft or by a sea-run skiff. During all surveys,
limnological samples were collected out of a small boat moored to
permanent sampling stations. The frequency of sampling was
designed to characterize the lake at three-week intervals from
ice-off in the spring to ice-on in the winter. The lake was
sampled for algal nutrients (nitrogen, phosphorus, silicon and
carbon) as for well as other water quality parameters (*see* Alaska
Department of Fish and Game, Lake Fertilization Guidelines) from
both the epilimnetic and mid-hypolimnetic zones. Water samples
from multiple (4) casts with a nonmetalic Van Dorn sampler were
pooled, stored in 8-to 10-liter transluscent carboys, cooled, and
immediately transported in light-proof containers to Sitka for
filtering and preservation. Subsequent filtered and unfiltered
water samples were stored (either refrigerated or frozen) in acid-
cleaned, prerinsed polybottles. The preprocessed water samples
were then sent to the Soldotna Limnology Laboratory for analysis.

All chemical and biological samples were analyzed by methods
detailed in Koenings et al. (1985). In general, filterable
reactive phosphorus (FRP) was analyzed by the molybdate-blue
ascorbic-acid method of Murphy and Riley (1962) as modified by
Eisenreich et al.
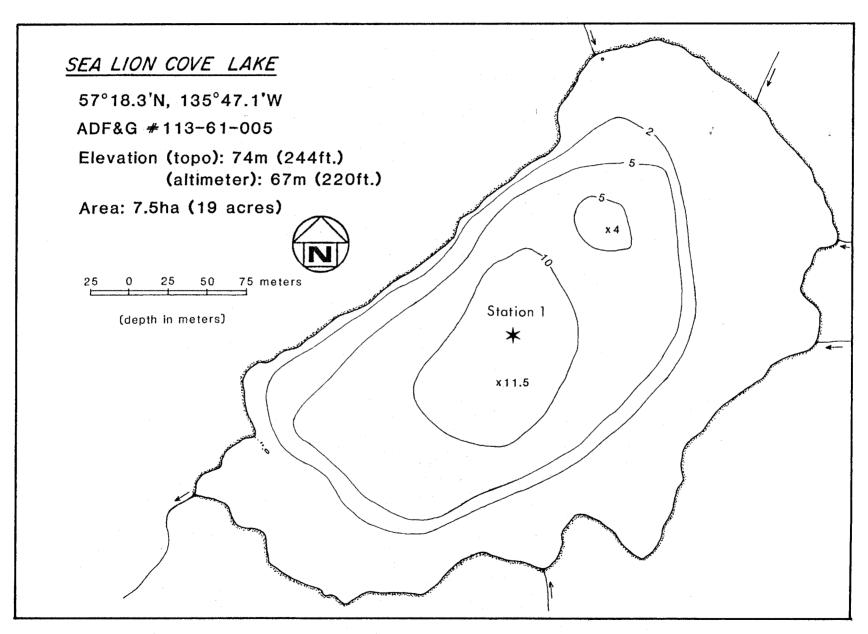
Figure 1. Morphometric map of Sea Lion Cove Lake showing the location of the major basins and the limnological sampling station.

(1975). Total phosphorus was determined by the FRP procedure after persulfate digestion. Nitrate and nitrite were determined as nitrite, after Stainton et al. (1977), following the cadmium reduction of nitrate. Ammonium analysis followed Stainton et al. (1977), using the phenolhypochlorite methodology, while reactive silicon analysis followed the procedure of Strickland and Parsons (1972). Alkalinity levels were determined by acid titration (0.02 N H_2SO_4) to pH 4.5, using a Corning model-399A specific ion meter.

Particulate carbon, nitrogen, and phosphorus were estimated directly from filtered seston prepared by drawing 1 to 2 liters of lake water through precleaned 4.2-cm GF/F filters. The filters were stored (frozen) in individually marked plexislides until analyzed.

Primary production (algal standing crop) was estimated by chlorophyll a (chl a) analysis, after the fluorometric procedure of Strickland and Parsons (1972). We used the low-strength acid addition recommended by Riemann (1978) to estimate phaeophytin. Water samples (1-2 liters) were filtered through 4.2-cm GF/F filters to which 1-2 mls of a saturated $MgCO_3$ solution were added just prior to the completion of filtration. The filters were then stored (frozen) in plexislides for later analysis.

Zooplankters were collected from duplicate bottom-to-surface vertical tows, using a 0.5-m diameter, 153-μ mesh, conical zooplankton net. The net was pulled at a constant 1 m/second and washed well before removing and preserving the organisms in 10% neutralized sugar-formalin (Haney and Hall 1973).

Identification within the genus *Daphnia* followed Brooks (1957); of the genus *Bosmina*, Pennak (1978); and of the copepods, Wilson (1959), Yeatman (1959), and Harding and Smith (1974). Enumeration consisted of counting triplicate 1-ml subsamples, which were taken with a Hensen-Stempel pipette, in a 1-ml Sedgewick-Rafter cell. Size (length) of the individual zooplankters was obtained

by counting at least 10 individuals along a transect in each of the 1-ml subsamples used in identification and enumeration. Zooplankters were measured to the nearest 0.01 mm, as described in Edmondson and Winberg (1971).

Bottom profiles were recorded with a fathometer along several lake transects, and from these depth recordings, bathymetric maps were developed. Using each map, the area of component depth strata was determined with a polar planimeter, and lake volume (V) was computed by summation of successive strata after Hutchinson (1957):

$$\text{Lake volume} = \sum_{i=1}^{n} \frac{h}{3} (A_1 + A_2 + \sqrt{A_1 A_2})$$

Where: $\sum_{i=1}^{n}$ = sum of strata volumes i through n

A_1 = surface area of upper depth strata (m^2)

A^2 = surface area of lower depth strata (m^2)

h = distance between A_1 and A_2 (m)

Lake mean depth ($\bar{z}$) was calculated as:

$$\bar{z} = V/AL$$

Where: $\bar{z}$ = lake mean depth (m)

V = lake volume $(\cdot 10^6 m^3)$

A_L = lake surface area $(\cdot 10^6 m^2)$

The theoretical water residence time (T_w) was calculated as:

$$T_w x \ (yr) = V/TLO$$

Where: T_w = theoretical water residence time (years)

V = total lake volume ($\cdot 10^6 m^3$)

TLO = total lake outflow ($\cdot 10^6 m^3 yr$)

The collection of physical data included the periodic (n=7-12) measurement of lake temperatures and light penetration profiles at the mid-lake sampling station. Lake temperature profiles were measured using a Hydro lab meter and/or pocket thermometer. These recordings were taken at depth increments from the surface to the lake bottom. The algal light-compensation point was defined as the depth at which 1% of the subsurface light (photosynthetically available radiation [400-700 nm]) penetrated (Schindler 1971) and was measured using a Protomatic submersible photometer. Recordings were taken at several depths between the surface and the compensation depth.

Using these data, the natural logarithm of light intensity was plotted against depth, and the slope of this line was used to calculate the light-extinction coefficient by date. In addition, water transparency was estimated, using a 20-cm Secchi disk.

Finally, in the Tables and Figures we have used the designation of either mg L^{-1} or μg L^{-1} to report concentration data. However, in the body of the report we have used either parts per million (ppm) in lieu of mg L^{-1} or parts per billion (ppb) in lieu of mg L^{-1}. We have made this conversion in order to reduce the handling time of the report by our support staff.

RESULTS

Light Regimes

The euphotic zone in Sea Lion Cove Lake varied considerably on
both a seasonal and annual basis. The general seasonal pattern
(Table 1) for light penetration follows: greatest during the
spring, progressively shallowed as the summer progressed, and then
slightly deepened beginning in late fall during the turnover
period. In particular, light penetrated to 9.2 m in the spring
period (May) of 1980, decreased to 8.8 m during the same time
period in 1982, and further shallowed to 7.8 m in the spring of
1983. Further, by late summer the euphotic zone had decreased to
only 5.5 m in 1980, remained deep at 7.3 m in 1982, and then
shallowed to only 3.5 m in 1983. The ratio of the deepest light
penetration within a year to the shallowest within the same year
was usually greater than or equal to 2:1.

On an annual seasonal basis (May-November), the euphotic depth
averaged 6.6 m in 1980, 7.9 m in 1982, and 6.1 m in 1983. Thus,
when comparing seasonal means, the depth of the euphotic zone
ranged from 7.9 m to 6.1 m, or a ratio of 1.3:1. Finally, the
depth of the euphotic zone, as estimated by Secchi-disk
measurement, was consistently less than that estimated by
submarine photometer. In 1980 the Secchi-disk depth was 86% of
the depth of the euphotic zone, in 1982 it decreased to 69%, and
in 1983 it increased slightly to 79%.

Temperature Profiles

The seasonal thermal-structure pattern of Sea Lion Cove Lake is
generally characterized by the formation of a stable thermocline
by the first part of June and by a fall turnover (dispersion)
period that begins as early as the end of September and is well
underway by the middle of October.

Table 1. Seasonal variation in light penetration as measured at the mid-lake station on Sea Lion Cove Lake, 1980-83, and expressed as the compensation depth, vertical extinction coefficient (k), and Secchi disk depth.

Date	Compensation depth[1] (m)	Vertical extinction coefficient[2] (m^{-1})	Secchi disc depth[3] (m)
1980 - 05/21	9.2	0.50	7.75
06/11	9.2	0.50	8.0
07/01	7.5	0.61	6.1
08/06	5.5	0.84	5.5
09/04	5.5	0.84	4.2
10/08	4.5	1.02	4.5
11/11	4.75	0.97	3.5
1981 - 03/19	7.0	0.66	8.5
1982 - 03/18	4.5	1.02	-ice covered-
05/19	8.75	0.53	5.1
06/16	7.5	0.61	5.8
07/08	10.0	0.46	7.5
08/03	10.0	0.46	7.0
08/31	7.25	0.64	5.0
10/15	5.5	0.84	4.5
11/09	6.5	0.71	3.5
1983 - 03/23	7.3	0.63	7.5
04/18	7.0	0.66	6.5
05/18	7.8	0.59	5.0
06/09	7.0	0.66	6.0
07/07	8.5	0.54	4.5
08/10	6.75	0.68	---
09/08	3.5	1.32	4.5
10/06	4.3	1.07	5.0
11/09	5.0	0.92	4.0

[1]Compensation depth is the depth to which 1% of surface light penetrates the lake and thus, it delineates the bottom of the euphotic zone.

[2]The vertical extinction coefficient is calculated by the formula:
$$k = (\ln I_0 - \ln I_z)/z$$
Where: k = the vertical extinction coefficient;
$\ln I_0$ = the natural logarithm of the light intensity (foot-candles) at the surface;
$\ln I_z$ = the natural logarithm of the light intensity (foot-candles) at the compensation depth; and
z = the compensation depth in meters.

[3]Depth at which Secchi disc is no longer visible from the surface.

The lake generally is extremely well mixed during both the spring and fall periods; isothermal conditions existed well beyond 4°C and the entire lake was still mixing at 8°C (Figure 2).

Epilimnetic temperatures rose quickly by the first part of June, reaching 14°-16°C by the beginning of July. These surface temperatures persisted through July, August, and the first part of September. Thereafter, the lake cooled quickly to 8°C; at which time, wind-generated currents continued to mix the lake from the top to bottom. After isothermal conditions were established in October, the entire lake volume cooled to 2°C by March of the following year when it was covered in ice; however, when the lake remained free of ice over the winter, the lake cooled to 4°C. Finally, hypolimnetic temperatures were often elevated beyond 4°C, reaching between 6° and 10°C. The lower layers were warmed through wind-generated mixing of the entire lake volume at 6°-8°C during the spring overturn period, and these temperatures persisted through the summer period.

Dissolved Gases

Dissolved oxygen (D.O.) concentrations within the epilimnion (1 m) were consistently between 9.5 and 14.3 ppm over the three years seasonal patterns were established (Table 2). Percent-saturation values tended to be close to 100%; low levels were usually above 90% of saturation (with one 84% of saturation value found on 18 April 1983), and high saturation values never exceeded 110% of saturation.

In contrast, within the hypolimnion D.O. levels taken near the bottom of the center basin underwent a gradual reduction after the spring overturn period. During 1980 and 1983, minimal values were recorded during September (prior to fall overturn) at 5.8 (50% of saturation) and 4.5 ppm (40% of saturation), respectively. However, in 1982 D.O. levels remained above 8.7 ppm (75% of saturation) throughout the summer period.
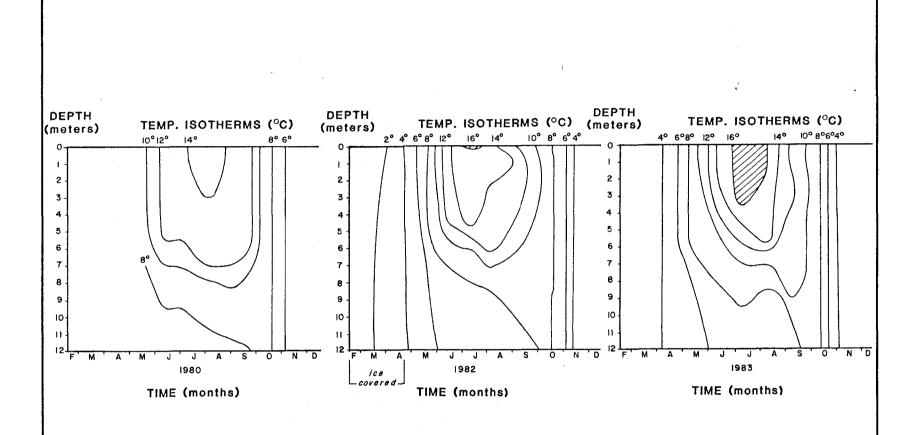
Figure 2. Thermal isopleths of Sea Lion Cove Lake as determined from depth profiles taken at the mid-lake in 1980, 1982, and 1983.

Table 2. Seasonal change in the concentration and percent saturation of dissolved oxygen within the epilimnion and hypolimnion of Sea Lion Cove Lake as measured at the mid-lake sampling station, 1980-1983.

| | Date | Epilimnion (1m) | | Mid-hypolimnion | | |
		Concentration (mg L^{-1})	Saturation (%)	Depth (m)	Concentration (mg L^{-1})	Saturation (%)
1980	21 May	11.0	99	10.0	11.1	94
	11 June	10.0	93	10.0	9.8	83
	1 July	9.8	94	10.0	8.7	76
	5 Aug.	10.4	107	9.0	7.8	71
	3 Sept.	9.9	94	9.5	5.8	50
	7 Oct.	10.6	94	8.0	10.6	94
	11 Nov.	11.9	93	8.0	11.2	88
1981	19 March	12.5	98	8.0	11.8	90
1982	18 March	13.8	94	7.0	11.4	84
	19 May	12.8	108	8.5	12.3	99
	15 June	9.8	93	8.0	9.6	80
	8 July	11.0	110	7.5	12.3	107
	3 Aug.	10.7	102	9.0	8.7	75
	31 Aug.	9.5	92	8.0	9.5	81
	15 Oct.	12.3	103	7.5	13.2	112
	8 Nov.	13.7	105	10.0	14.0	108
1983	25 March	12.3	91	8.0	11.4	86
	18 April	10.5	84	8.0	11.3	91
	18 May	11.6	105	9.0	10.5	87
	9 June	10.2	100	7.5	10.6	94
	7 July	9.9	103	8.0	9.6	82
	10 Aug.	10.5	107	8.0	9.0	78
	8 Sept.	11.4	106	10.5	4.8	40
	6 Oct.	12.3	107	8.0	12.9	112
	9 Nov.	14.3	106	8.0	14.7	109

Variable sampling depths may have influenced the absolute D.O.
values, especially within the hypolimnion, but generally, the
overall trend was for hypolimnetic oxygen concentrations and
percent-saturation values to be below those of the epilimnion,
especially during the late summer period. However, on all dates
and at all depths sampled, oxygen concentrations were well above
those required for the survival of eggs and/or rearing fry.

General Water Quality Indicators

Sea Lion Cove Lake water quality is exemplified by a lack of ions,
as indicated by a consistently low conductivity ($\cong 27$ μmhos cm^{-1}),
low dissolved solids ($\cong 22$ ppm), and extremely weak alkalinity
values of between 4 to 8 ppm as $CaCO_3$ (Tables 3 and 4).
Large-scale, seasonal variation within these parameters were rare;
major increases or decreases were caused by differences related to
depth. That is, changes occurring in water quality were due, in
large part, to reduced D.O. levels in the hypolimnion, producing
redox changes that increased/decreased the above parameters (e.g.,
3 September 1980.)

The generally low levels of dissolved ions are also reflected in
the barely detectable levels (<0.3 ppm) of magnesium and the
persistently low concentrations of calcium (0.9 ppm to 2.5 ppm).
In contrast to the low levels of calcium and magnesium, iron
concentrations were higher than other well-oxygenated, clear-water
lake systems. That is, anticipated iron levels of approximately
20 ppb were often exceeded within both the hypolimnion and the
epilimnion. However, like clear-water systems, epilimnetic iron
levels were less than those found within the hypolimnion during
the same sampling date, except for both the spring and winter
turnover periods. Finally, in response to generally reduced
oxygen levels, iron levels within the hypolimnion increased with
the progression of summer. For example, in 1983 when oxygen
levels decreased from 91% of saturation in April to 40% of

Table 3. Seasonal changes of general water quality parameters and nutrient concentrations within the epilimnion and hypolimnion of Sea Lion Cove Lake determined from samples collected at the mid-lake station, 1980-81.

| | 1980 | | | | | | | | | | | | | | 1981 | |
| Sampling date: | 22 May | | 12 June | | 3 July | | 5 Aug. | | 3 Sept. | | 7,8 Oct. | | 11 Nov. | | 19 March | |
Depth:	1m	10m	1m	9m	1m	10m	1m	9m	1m	9.5m	1m	8m	1m	8m	1m	8m
Parameter																
Conductivity (umhos L^{-1})	30	26	27	27	27	29	27	27	28	32	25	25	26	26	16.5	16.6
pH	6.6	6.4	6.6	6.5	6.7	6.2	6.2	6.0	6.4	5.9	6.4	6.4	6.1	6.1	6.4	6.4
Alkalinity (mg L^{-1})	3.0	3.0	5.0	4.5	5.0	3.5	4.0	4.0	6.5	8.0	5.0	4.5	3.0	3.0	4.5	4.0
Calcium (mg L^{-1})	1.7	0.9	1.7	1.7	1.7	1.6	2.5	1.6	1.7	1.4	1.5	0.7	1.7	1.6	1.3	1.3
Magnesium (mg L^{-1})	<0.3	0.9	<0.3	0.5	0.8	0.8	0.8	0.5	0.4	0.9	0.6	0.6	<0.3	<0.3	<0.3	<0.3
Iron (ug L^{-1})	11	56	31	41	--	86	64	103	61	225	100	104	--	--	46.4	60.9
Hardness (mg L^{-1})	5.5	6.1	5.5	6.4	7.5	7.4	9.7	6.2	6.0	7.6	6.4	4.4	5.5	5.2	4.6	4.6
Total dissolved solids (mg L^{-1})	26	--	7	--	16	--	20	23	28	27	22	18	23	28	--	--
Total phosphorus (ug L^{-1})	4.4	3.7	4.6	3.7	4.1	5.5	6.9	5.0	10.1	6.7	7.8	9.5	9.5	5.9	3.2	6.7
Total filterable phosphorus (ug L^{-1})	1.9	2.3	1.4	1.9	2.4	2.6	5.2	2.9	4.9	5.5	6.1	3.4	4.1	3.1	4.0	4.1
Filterable reactive phosphorus (ug L^{-1})	2.1	1.6	1.3	--	1.9	2.0	1.9	2.1	2.2	4.4	3.6	2.6	2.7	3.0	3.2	3.9
Nitrate and Nitrite (ug L^{-1})	34	44	20	36	14	36	11	9	15	52	46	45	65	65	64.0	62.1
Ammonium (ug L^{-1})	11	12	10	6	11	18	5	14	5	35	18	12	19	30	9.3	3.6
Kjeldahl N (ug L^{-1})	Not determined															
Reactive silicon (ug L^{-1}) *	1693	1554	2347	2393	2330	2418	2285	2217	2224	2212	2203	2272	2347	2388	2529	2522

* All silicon values rounded to nearest whole number.

Table 4. Seasonal changes of general water quality parameters and nutrient concentrations within the epilimnion and hypolimnion of Sea Lion Cove Lake as measured at the mid-lake sampling station, 1982.

| Sampling date: | 18 March | | 19 May | | 16 June | | 7,8 July | | 3 Aug. | | 31 Aug. | | 15 Oct. | | 9 Nov. | |
Depth:	1m	7m	1m	8.5m	1m	8m	1m	7.5m	1m	9m	1m	8m	1m	7.5m	1m	8m
Parameter																
Conductivity (umhos L^{-1})	29	24	24	24	22	21	28	27	29	27	28	27	25	25	26	26
pH	6.0	6.1	6.6	6.6	6.8	6.5	6.7	6.4	6.8	6.1	6.7	6.2	6.2	6.3	6.2	6.2
Alkalinity (mg L^{-1})	3.0	5.0	5.0	5.0	5.0	4.0	5.0	5.0	5.0	4.0	5.0	5.0	4.0	4.5	4.0	4.0
Calcium (mg L^{-1})	1.7	1.7	2.3	2.3	1.3	0.9	0.8	0.8	0.8	0.8	1.3	0.8	1.9	1.9	1.6	1.6
Magnesium (mg L^{-1})	1.7	3.4	<0.5	<0.5	<0.5	<0.5	0.3	0.3	0.6	0.6	0.9	0.9	<0.5	<0.5	<0.5	<0.5
Iron (ug L^{-1})	65.0	36.4	53.7	26.1	38.9	58.0	25.2	35.1	31.4	94.2	38.7	81.7	101.0	110.0	96.8	95.6
Hardness (mg L^{-1})	11.3	18.3	7.9	7.8	5.4	4.4	3.3	3.3	4.5	4.6	7.0	5.8	7.0	7.0	6.2	6.2
Total dissolved solids (mg L^{-1})	Not determined															
Total phosphorus (ug L^{-1})	4.8	4.3	6.1	7.6	6.0	6.1	10.4	10.2	8.4	6.1	12.2	5.0	7.5	5.7	12.3	5.2
Total filterable phosphorus (ug L^{-1})	4.5	1.9	2.6	2.1	2.1	2.0	3.5	2.2	13.4	7.6	7.4	2.3	4.6	3.2	5.3	2.9
Filterable reactive phosphorus (ug L^{-1})	2.6	1.7	2.6	2.0	2.0	1.8	1.6	1.6	6.1	4.6	1.8	1.6	2.1	1.8	3.8	2.5
Nitrate and Nitrite (ug L^{-1})	81.6	78.6	59.2	66.8	35.4	57.8	9.9	47.7	19.1	48.6	25.3	44.3	39.3	49.8	61.2	61.0
Ammonium (ug L^{-1})	26.8	22.1	2.2	1.9	3.9	4.4	2.4	4.1	8.4	13.3	3.8	10.4	7.8	5.5	5.0	4.5
Kjeldahl N (ug L^{-1})	46.6	47.7	79.0	93.0	81.4	76.8	161.5	115.8	87.1	70.9	103.4	70.9	109.2	89.5	74.4	62.8
Reactive silicon (ug L^{-1}) *	1914	2830	2048	698	2130	1714	2308	2197	2188	2026	1822	1778	2284	2245	2175	2242

* All silicon values rounded to the nearest whole number.

saturation in September, iron concentrations rose from 65 to 770 ppb, respectively.

In general the pH was found to be slightly on the acid side of neutral. Values ranged from 5.9 to 6.7 units in 1980 and from 6.0 to 6.7 units in 1982. On all dates and depths sampled, pH values were well within the range acceptable to protect eggs and/or rearing salmonids.

Nutrient Cycles

The algal nutrients of particular interest are carbon (alkalinity), phosphorus, nitrogen, and (for the growth of diatoms) silicon. Overall, reactive-silicon levels found in Sea Lion Cove Lake were relatively high when compared to concentrations observed in other southeast Alaskan lakes. During 1980, reactive-silicon levels centered around 2,200 ppb; generally, lower values were found in the epilimnion than in the hypolimnion during both the spring (June-July) and fall (October-November) periods (Figure 3). However, during early August and September, epilimnetic concentrations of reactive silicon exceeded those found within the hypolimnion. Finally, we observed a seasonal pattern of low silicon concentrations during the late winter that was followed, in sequence, by a major increase during early spring, a slight drop during the summer period, and then by an increase to spring levels during the fall-to-early winter period.

Except for low values reported for both the epilimnion and hypolimnion on 31 August (Figure 3), this pattern repeated itself during 1982. Similar low values were previously reported for Falls Lake, Alaska (Koenings et al. 1984) during the same time period and were probably caused by the inadvertent freezing of the combined samples during shipment to Soldotna. Nonetheless, reactive-silicon levels were consistently high ($\cong$ 2000 ppb) throughout 1982, and the seasonal pattern of epilimnetic levels were less than those observed to occur in the hypolimnion.
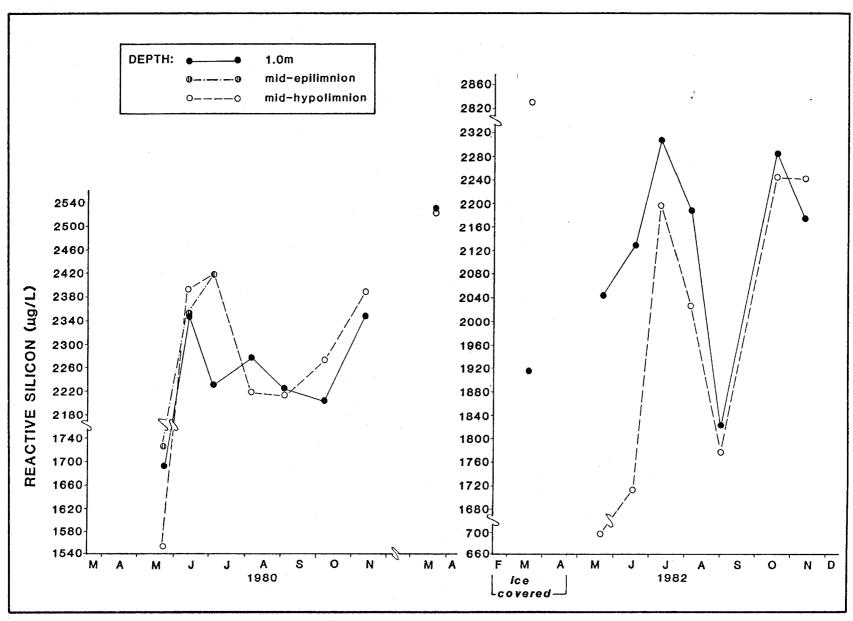
Figure 3. Seasonal variation in the concentration of reactive silicon within the 1.0-m mid-epilimnion and hypolimnion of Sea Lion Cove Lake, 1980-81 and 1982.

In contrast to reactive-silicon levels, inorganic-nitrogen (ammonium and nitrate + nitrite) concentrations were low throughout 1980 and 1982 (Tables 3 and 4). In particular, during 1980 nitrate + nitrite concentrations ranged between 9 and 65 ppb and had generally lowered values during the July through August period in both the epilimnion and the hypolimnion (Figure 4). However, except for 5 August 1980, levels of nitrate + nitrite in the epilimnion were less than those observed to occur in the hypolimnion. This is the same time period in which reactive-silicon levels of the epilimnion exceeded those of the hypolimnion. Similarly, we observed that ammonium concentrations within the hypolimnion exceeded those within the epilimnion, especially during the summer stratification period.

Confirmation of the seasonal pattern established in 1980 was obtained in 1982 (Figure 5). Here too, levels of epilimnetic inorganic nitrogen were consistently less than those found occurring in the hypolimnion, especially after the lake became thermally stratified. However, in contrast to the pattern established for the inorganic forms of nitrogen, we observed Kjeldahl nitrogen concentrations within the epilimnion to be consistently greater than those observed within the hypolimnion. Further, the concentration of nitrate + nitrite was exceptionally low on 7-8 July, when Kjeldahl nitrogen values were particularly high. As a major portion of the Kjeldahl nitrogen is organic nitrogen (given the consistently low >10 ppb concentration of ammonium), the observed pattern is consistent with the uptake of inorganic nitrogen by the phytoplankton, which forms a major fraction of particulate organic nitrogen. As such, the observed pattern in inorganic-organic nitrogen levels within the epilimnion serves to typlify nutrient dynamics when algal utilization of an inorganic nutrient exceeds its resupply.

Phosphorus levels are of critical importance because of the general correlation between total phosphorus (total-P) loading and
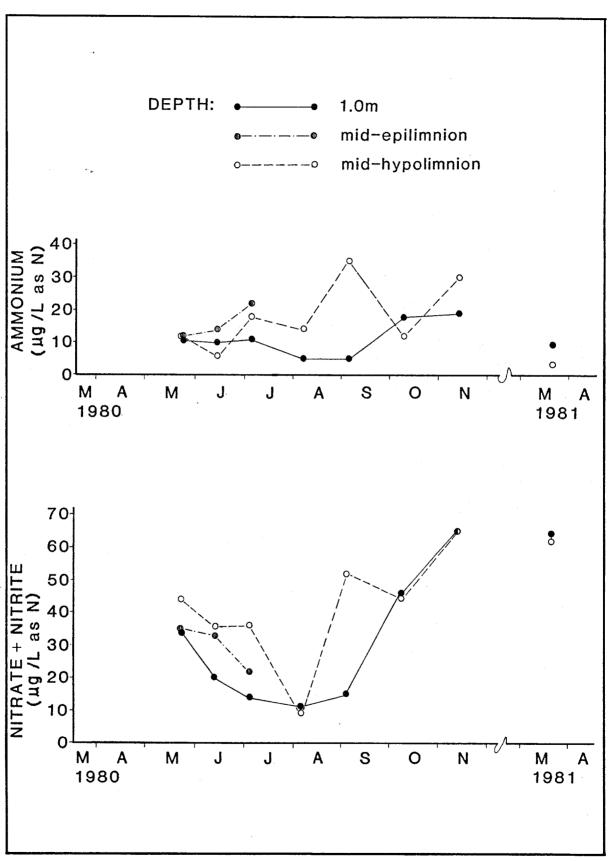
Figure 4. Seasonal variation in the concentration of nitrogen within the 1.0 m, mid-epilimnion, and hypolimnion of Sea Lion Cove Lake, 1980-81.
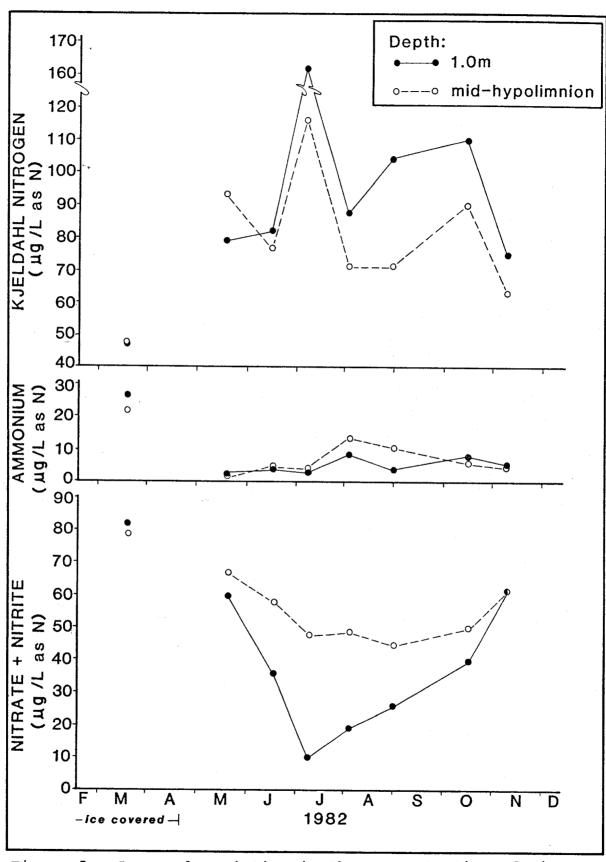
Figure 5. Seasonal variation in the concentration of nitrogen within the 1.0 m and hypolimnion of Sea Lion Cove Lake, 1982.

resultant summer-period primary production, or standing crop of algae (Vollenweider 1976). In 1980 total-P levels in the epilimnion increased from levels, approaching 4 ppb in the spring to levels exceeding 10 ppb on 3 September; these levels were followed by only a slight decline to between 7.8 and 9.5 ppb by early winter (Figure 6). This same general pattern was repeated in 1982, except that total-P levels were somewhat elevated; i.e., the spring total-P levels, which were approximately 6 ppb, were followed by an increase to over 10 ppb by the beginning of July. Thereafter, epilimnetic total-P concentrations fluctuated around 10 ppb and exceeded 12 ppb during August and November (Figure 7). Finally, in both 1980 and 1982, total-P concentrations within the epilimnion tended to exceed those found within the hypolimnion.

During 1980 filterable reactive phosphorus (FRP) concentrations were always detectable (>0.5 ppb) within the epilimnion, ranging from 1.3 to 3.6 ppb (Table 3). In general, higher FRP values were found in the fall, and lower concentrations were found in the spring and early summer. In 1982 FRP levels remained high, ranging from 1.6 to 3.8 ppb; seasonally minimal values occurred in July and August; whereas, in 1980 seasonally low values were observed in June, July, and August. Overall, we observed little consistent difference between hypolimnetic and epilimnetic FRP concentrations.

In 1980 FRP represented from 22% to 46% of the total-P in the epilimnion; this compares to the 15% to 43% of total-P in the same time period in 1982. Similarly, particulate phosphorus (part-P) represented from 22% to 85% of total-P in 1980 and from 39% to 66% of total-P in 1982. Generally, levels of FRP and of part-P were inversely related because inorganic phosphorus (FRP) was utilized for growth by phytoplankton and bacteria (part-P). However, the fractions of phosphorus that showed the most consistent pattern for 1980 and 1982 (responsible for a major portion of the increase in total-P during July through November) were filterable unreactive phosphorus (FUP) or nonparticulate organic phosphorus.

-44-
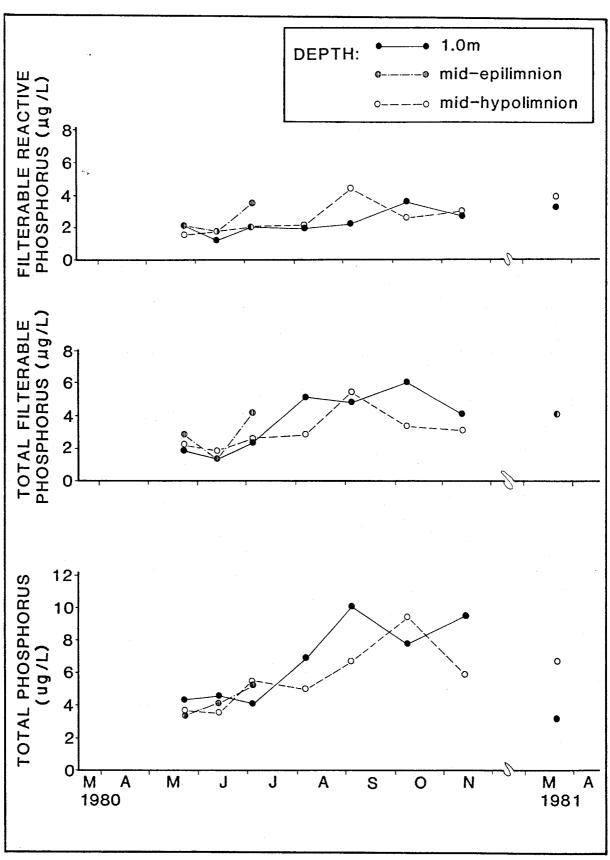
Figure 6. Seasonal variation in the concentration of phosphorus within the 1.0 m, mid-epilimnion, and hypolimnion of Sea Lion Cove Lake, 1980-81.
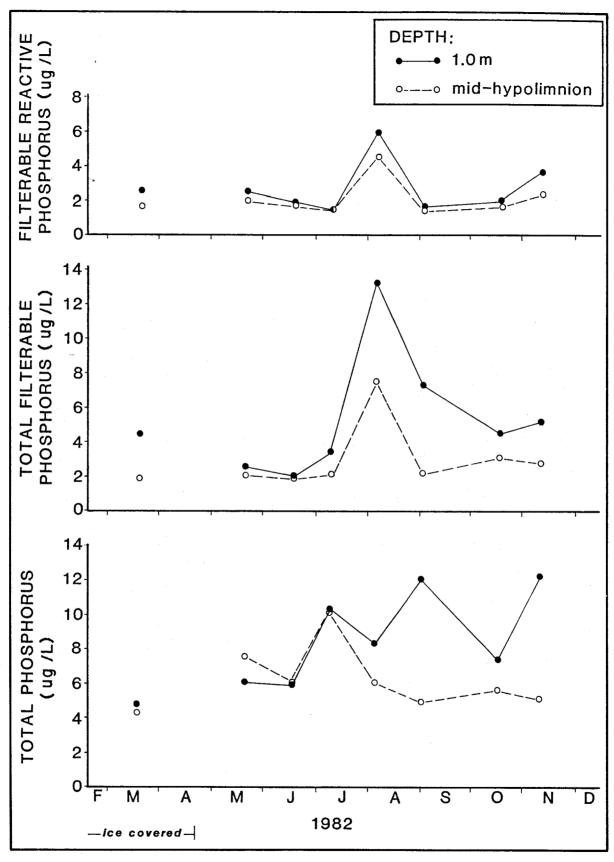
Figure 7. Seasonal variation in the concentration of phosphorus
within the 1.0 m and hypolimnion of Sea Lion Cove Lake,
1982.

As FUP was a major-P pool (or sink accumulating phosphorus) during the summer period, we were interested in the dynamics of its formation. FUP was low in the spring of 1980, ranging from 0% of total-P in May to nearly 12% by 3 July. Thereafter, FUP increased to represent nearly 50% of the total-P in the epilimnion; this was followed by a gradual decline to 15% of total-P by November. During 1982 the cycle was basically the same; i.e., low levels of FUP in the spring (0% to 18% of total-P) were followed by a major pulse in August (50% of total-P) and then by a gradual depletion to 12% of total-P by November. Further, total-P levels within the hypolimnion were generally less than those observed within the epilimnion, especially during the summer months of 1982 (Figure 7). Since FRP within both strata during 1982 was extremely similar, the difference between the two strata (in terms of total-P) was caused by elevated levels of FUP; this points to the epilimnion as the major source of this fraction. Thus, as the seasonal onset of major increases in FUP was quite closely linked to the standing crop of phytoplankton (chl a) and as the major strata showing an acute accumulation of FUP was the epilimnion, the source of FUP apparently was the biota (plankton) occupying the epilimnion of the lake.

Nutrient Ratios

The ratio of inorganic nitrogen (ammonium and nitrate + nitrite) to total-P changed seasonally in Sea Lion Cove Lake, especially within the epilimnion (Table 5). During 1980, N:P ratios fell soon after May from 23:1 to 13:1 by July; minimal values of 4:1 were reached in September. However, during October and November, the N:P ratio rose to 20:1 as a result of both a resupply of inorganic nitrogen to the surface layer during the fall overturn and a decrease in biological activity as lake temperatures cooled.

Table 5. The ratio of inorganic nitrogen
(ammonium and nitrate + nitrite)
to total phosphorus concentration
(by atoms) within the epilimnion
and hypolimnion of Sea Lion Cove
Lake, as measured at the mid-lake
station, 1980-1983.

| Date | Inorganic Nitrogen:Phosphorus (by atoms) | |
	Epilimnion (1.0 m)	Mid-hypolimnion (7.5 m-10.0 m)
05/22/80	23:1	33:1
06/12/80	14:1	25:1
07/03/80	13:1	22:1
08/05/80	5:1	10:1
09/03/80	4:1	29:1
10/07-10/08/80	18:1	13:1
11/11/80	20:1	36:1
03/19/81	51:1	22:1
03/18/82	50:1	52:1
05/19/82	22:1	20:1
06/16/82	14:1	23:1
07/07-07/08/82	3:1	11:1
08/03/82	7:1	22:1
08/31/82	5:1	24:1
10/15/82	14:1	21:1
11/09/82	12:1	28:1

In 1982 the pattern established in 1980 was repeated with high ratios forming in the spring (50:1) and followed by severely reduced values as early as July. Low N:P ratios (3:1 to 7:1) persisted through August and into the first part of September. Thereafter, the atom ratios rose to 14:1 and 12:1 during October and November, respectively.

The seasonal depletion of inorganic nitrogen caused by phytoplankton demand exceeding nutrient supply resulted in a lower N:P ratio within the epilimnion. In addition, a similar drop in the N:P ratio was not observed within the hypolimnion, except on isolated occasions during the summer of both 1980 and 1982 when thermal stratification was particularly strong.

Algal Biomass

The standing crop, or biomass, of phytoplankton (as chlorophyll a [chl a]) 1 exhibited three distinct seasonal patterns, one for each year of study (Table 6). During 1980 the chl a within the surface stratum peaked in early September at 1.35 ppb. This seasonal peak was preceded by minimal values in the spring (0.40 ppb) and was followed by relatively large concentrations (0.74 to 0.99 ppb) that persisted through November. The seasonal mean chlorophyll a concentration equalled 0.86 ppb.

In comparison, during 1982 chl a levels were extremely low, ranging from 0.04 to 0.37 ppb; the seasonal peak concentrations appeared in November. However, from late May through August, chl a levels were barely detectable; i.e., <0.003 to 0.06 ppb. Thereafter, algal biomass rose to 0.37 ppb, which only equalled the minimal values recorded in 1980. Consequently, the seasonal mean chlorophyll a concentration for 1982 equalled 0.13 ppb, which was only 15% of that found in 1980.

Table 6. The seasonal variation in algal standing crop as estimated by chlorophyll a (chl a) concentrations within the epilimnion and at the light compensation-point in Sea Lion Cove Lake, 1980-83.

| Date | Epilimnion (1 m) | | Compensation point | | Depth (m) |
	Chlorophyll a (μg L^{-1})	Phaeophytin (μg L^{-1})	Chlorophyll a (μg L^{-1})	Phaeophytin (μg L^{-1})	
1980					
05/22	0.40	--	N.A.	N.A.	
06/12	0.81	--	N.A.	N.A.	
07/03	0.75	0.03	N.A.	N.A.	
08/05	1.00	--	1.5	--	5.5
09/03	1.35	0.5	1.28	0.06	5.5
10/07	0.74	--	0.72	--	4.5
11/11	0.99	0.15	1.07	--	4.75
1981					
03/19	0.79	0.11	N.A.	N.A.	
1982					
03/18	0.01	0.03	0.02	0.06	4.5
05/19	0.04	0.08	0.06	0.16	8.5
06/16	<0.003	0.04	0.003	0.12	7.5
07/07	0.02	0.12	0.04	0.39	10.0
08/03	0.06	0.15	0.05	0.39	10.0
09/01	0.20	0.30	0.13	0.66	7.25
10/14	0.07	0.24	0.24	0.46	5.5
11/09	0.37	0.43	0.35	0.41	6.5
1983					
03/23	0.48	0.30	0.55	0.30	7.5
04/18	0.92	0.42	0.70	0.40	7.5
05/18	1.05	0.58	1.93	1.04	7.75
06/09	1.40	0.17	1.06	0.95	7.0
07/07	0.57	0.34	2.02	1.13	8.0
08/10	0.51	0.40	0.66	1.13	7.0
09/08	0.31	0.34	0.29	0.38	3.25
10/06	0.37	0.36	0.22	0.41	5.0
11/09	0.75	0.40	0.66	0.40	5.0

Finally, in 1983 algal biomass rose to levels equal to or greater than those found in 1980. However, peak chl a levels (1.40 ppb) were observed in June; and relatively high pigment concentrations, throughout April and May. After June chl a levels decreased, reaching seasonally low levels in September (0.31 ppb). Finally, seasonal-mean chl a levels were 0.71 ppb, a major increase over that found in 1982.

In terms of amount, algal pigment concentrations in 1983 resembled those in 1980; however, instead of peaking in August and September, these concentrations peaked early in the spring. However, in 1980 and 1983, spring pigment concentrations were relatively high when compared to seasonal peaks. In contrast, chl a concentrations in the spring of 1982 were almost nonexistent, and peak values in the fall approached the minimal chl a values for 1980 and 1983.

We observed pigment concentrations at the midpoint of the light attenuation curve and at the compensation point (or stratum), to which 1% of subsurface light had penetrated (Table 6). Not surprisingly, we observed that when the compensation point was well within the epilimnion, chl a concentrations at both the surface and at the 1% light level were virtually equivalent (e.g., 1980 measurements). However, even when the compensation point was located well within the hypolimnion (e.g., June-August 1983), chl a concentrations often exceeded those at the surface. Thus, algal production was not limited, in any sense, to the epilimnion but was controlled by the depth of the euphotic zone. This would allow algal production to occur below the zone of nutrient depletion (epilimnion) and, because of vastly different nutrient concentrations, ratios, and light regimes, allow a definite vertical separation of algal taxa.

Zooplankter Density and Body Size

Major taxa of macro-zooplankton within Sea Lion Cove Lake include
the cladoceran zooplankters (*Bosmina longirostris*, *Holopedium
gibberum*) and the copepod zooplankters (*Cyclops bicuspidatus
thomasi*, *Diaptomus kenai* and *Epischura nevadensis*.) Of ancillary
importance were species of *Daphnia* and chydoridae, because the
occurrence of these taxa within the lake was sporadic and
incidental to those of the major species. Several taxa of
rotifers were also observed to occur in the lake; namely,
Kellicottia longispina, *Conochilus* sp. and *Conochiloides* sp.

In 1980 the numerically dominant zooplankter was *Bosmina*, which
ranged from 25,089 organisms/m^2 in May to 363,729 organisms/m^2 in
October (Table 7). Thus, we found *Bosmina* densities to peak in
late fall, which also coincided with the highest density (3,744
organisms/m^2) for the herbivorous cladoceran, *Holopedium gibberum*.
In contrast to the seasonal dynamics of *Bosmina* and *Holopedium*,
the density of *Diaptomus* peaked in early spring (9,806/m^2); it was
followed by a gradual decline throughout the summer, reaching a
secondary peak in August. With the decline in *Diaptomus*,
Epischura densities increased, reaching a peak density (11,376/m^2)
in August. Numerically, the combined densities of *Diaptomus* and
Epischura were well below those of both *Bosmina* and *Cyclops*.
Cyclops densities ranged from a secondary peak of 57,310/m^2 in May
(minimal adult densities in July at 12,939/m^2) to a seasonally
high density of 169,562/m^2 in October. In summary, maximal
macro-zooplankton densities were observed to occur in October
because of seasonal peaks in the density of the dominant *Bosmina*
and the sub-dominant *Cyclops*. In addition, the calanoid
Epischura also exhibited seasonally high densities in August;
however, in contrast the density of *Diaptomus* peaked in May and
June.

Table 7. Zooplankton density (number per m^2) in Sea Lion Cove Lake estimated from vertical-tow samples at the mid-lake station, 1980.

			Sampling date				
Taxa	20 May	10 June	1 July	5 Aug.	3 Sept.	7 Oct.	11 Nov.
Bosmina sp.	25,089	43,505	80,795	96,281	142,639	363,729	47,122
Holopedium gibberum	0	0	713	1,248	2,318	3,744	891
Subtotal (Cladocera)	25,089	43,505	81,508	97,529	144,957	367,473	48,013
Calanoid copepods	14,009	10,188	5,807	19,613	8,915	5,349	2,547
Cyclopoid copepods	57,310	28,222	12,939	33,342	74,885	169,562	101,885
Copepod nauplii	1,274	0	1,325	4,101	0	0	1,656
Subtotal (adult copepods)	71,319	38,410	18,746	52,955	83,800	174,911	104,432
Kellicottia longispina	20,801	172,525	67,584	12,481	5,943	1,783	425
Conochilus sp.	24,961	0	0	0	0	0	0
Conochiloides sp.	607,998	47,546	0	0	0	0	0
Subtotal (zooplankters preferred by coho)	14,009	10,188	5,807	19,613	8,915	5,349	2,547

Using 1980 as a reference year, we found that the individual species followed similar seasonal density patterns in both 1981 (Table 8) and in 1982 (Table 9) and, in addition, maintained the relative numerical order that was established in 1980. However, the densities of individual taxa were different on a yearly basis. During 1980 seasonal-mean *Bosmina* densities equalled $114,166/m^2$ (n=7); whereas, during 1981 the seasonal-mean density dropped to $63,471/m^2$ (n=9) and finally was reduced to $39,672/m^2$ (n=10) in 1982. However, *Cyclops* densities were relatively constant, ranging from a seasonal mean of $68,306/m^2$ in 1980 to $48,268/m^2$ in 1982 and, finally, to a low of $41,089/m^2$ in 1981. The densities of *Diaptomus* and *Epischura* were consistently below those of both *Bosmina* and *Cyclops*. *Diaptomus* seasonal-mean densities exceeded $12,000/m^2$ in 1981 and reached $8,707/m^2$ in 1982 and $4,964/m^2$ in 1980. Likewise the seasonal-mean density of *Epischura* equalled nearly 8,000 organisms$/m^2$ in 1982, which was reduced to $4,526/m^2$ in 1980 and still further to only $3,019/m^2$ in 1981.

In contrast to the lower importance of both *Diaptomus* and *Epsichura* to the zooplankton community in terms of numerical density, the body sizes of both organisms were the largest recorded for any taxa (Tables 10 and 11). Calanoid body sizes on the average were over double those of both *Bosmina* and of *Cyclops*. In 1981 calanoid zooplankton ranged in average size from 0.77 mm in the spring to more than 1.70 mm by the end of July. At the same time individuals were recorded with a body size that exceeded 2.00 mm. In contrast, the largest mean body size of *Cyclops* never exceeded 0.77 mm, and individual body sizes rarely exceeded 0.90 mm. Still smaller were *Bosmina*, which reached the largest mean body size of 0.56 mm in May but tended to center around 0.51 mm for most of the season. Individual *Bosmina* body sizes ranged from 0.33 to 0.69 mm; individuals that were larger than the lowest body size recorded for any individual calanoid were somewhat rare.

Table 8. Zooplankton density (number per m^2) in Sea Lion Cove Lake estimated from vertical-tow samples at the mid-lake station, 1981.

					Sampling date					
Taxa	19 March	27 May	19 June	30 June	13 July	24 July	27 Sept.	2 Oct.	10 Oct.	16 Oct.
Bosmina sp.	4,712	38,844	49,032	63,466	60,920	57,096	122,898	100,611	44,404	33,964
Holopedium gibberum	0	0	596	637	107	426	0	0	0	0
Daphnia sp.	87	0	0	0	0	0	0	0	0	0
Chydornae	128	0	0	0	0	0	0	0	0	0
Subtotal (Cladocera)	4,927	38,844	49,628	64,103	61,027	57,552	122,898	100,611	44,404	33,964
Calanoid copepods	20,759	33,326	26,447	17,830	20,377	23,772	5,094	10,402	4,796	1,699
Cyclopoid copepods	62,532	17,407	22,288	14,432	9,974	12,099	82,358	65,800	71,574	73,867
Copepod nauplii	10,570	637	0	3,820	5,049	9,340	0	0	0	510
Subtotal (adult copepods)	83,291	50,733	48,735	32,262	30,351	35,871	87,452	76,202	76,370	75,566
Kellicottia longispina	1,907	10,401	87,961	198,803	37,570	46,273	2,547	4,246	7,005	3,566
Conochilus sp.	0	5,795	0	0	0	0	0	0	0	0
Conochiloides sp.	5,094	507,705	275,472	193,454	64,103	19,953	0	3,821	3,566	2,386
Subtotal (zooplankters preferred by coho)	20,846	33,326	26,447	17,830	20,377	23,772	5,096	10,402	4,796	1,699

Table 9. Zooplankton density (number per m^2) in Sea Lion Cove Lake estimated from vertical-tow samples at the mid-lake station, 1982.

Taxa	Sample date										
	17 March	18 May	3 June	16 June	7 July	20 July	3 Aug.	2 Sept.	7 Oct.	14 Oct.	9 Nov.
Bosmina sp.	510	4,033	12,736	18,622	48,140	71,320	26,957	154,526	9,976	14,773	0
Chydornae	0	212	0	0	0	0	0	0	0	0	0
Subtotal (Cladocera)	510	4,245	12,736	18,622	48,140	71,320	26,957	154,526	9,976	14,773	0
Diaptomus sp.	9,510	19,104	12,736	16,047	16,047	17,830	5,306	0	0	0	0
Epischura sp.	0	0	0	0	2,972	9,510	32,900	8,618	11,038	7,005	4,585
Cyclopoid copepods	71,490	42,664	38,207	54,381	21,990	19,612	14,434	92,715	85,328	71,065	42,282
Copepod nauplii	20,716	7,217	2,972	0	4,160	9,212	5,731	2,080	0	382	21,615
Subtotal (adult copepods)	81,000	61,768	50,943	70,428	41,009	46,654	52,640	101,333	96,366	78,070	46,867
Kellicottia longispina	15,962	9,977	52,428	304,890	230,897	158,983	75,352	11,589	4,882	3,057	1,401
Conochiloides sp.	2,377	113,984	206,317	279,929	0	0	0	0	0	0	0
Subtotal (zooplankters preferred by coho)	9,510	19,104	12,736	16,047	19,019	27,340	38,206	8,618	11,038	7,005	4,585

Table 10. Seasonal mean body size (length) and mean body size plus range by date for cladoceran and copepod zooplankters in Sea Lion Cove Lake, 1981.

Taxa and length statistics (mm)	Sampling date									Total range and seasonal weighted mean
	3/19	5/27	6/9	6/30	7/13	7/24	9/27	10/2	10/10,16*	
CLADOCERA										
Bosmina sp.										
range	0.33–	0.36–	0.41–	0.38–	0.43–	0.39–	0.43–	0.38–	0.41–	0.33–
	0.48	0.66	0.66	0.69	0.66	0.60	0.58	0.61	0.58	0.69
mean	0.39	0.56	0.52	0.51	0.51	0.50	0.51	0.51	0.51	0.51
std. dev.	0.04	0.09	0.09	0.08	0.05	0.06	0.04	0.06	0.06	––
Daphnia sp.										
range	0.41–	0	0	0	0	0	0	0	0	0.41–
	0.69									0.69
mean	0.55	0	0	0	0	0	0	0	0	0.55
std. dev.	0.10	0	0	0	0	0	0	0	0	––
Holopedium gibberum										
range	0	0	0.86–	1.14[†]	1.25[§]	0	0	0	0	0.86–
			1.02							1.24
mean	0	0	0.93	1.14	1.25	0	0	0	0	1.05
std. dev.	0	0	0.08	––	––	0	0	0	0	––
COPEPODA										
Calanoid copepods										
range	0.66–	1.32–	1.40–	1.17–	1.37–	0.77–	1.22–	1.07–	1.02–	0.66–
	0.97	2.03	1.91	1.88	2.01	1.89	1.88	1.80	1.85	2.03
mean	0.77	1.61	1.61	1.56	1.70	1.71	1.53	1.39	1.40	1.55
std. dev.	0.11	0.17	0.18	0.19	0.18	0.23	0.27	0.25	0.28	––
Cyclopoid copepods										
range	0.61–	0.53–	0.64–	0.58–	0.58–	0.41–	0.48–	0.48–	0.51–	0.42–
	0.84	0.89	0.79	0.84	0.84	0.88	0.91	0.79	0.61	0.91
mean	0.70	0.77	0.73	0.72	0.74	0.70	0.67	0.58	0.57	0.65
std. dev.	0.05	0.09	0.05	0.07	0.07	0.14	0.16	0.08	0.03	––

* Data from both dates combined.
† Only two organisms in sample.
§ Only one organism in sample.

Table 11. Seasonal mean body size (length) and mean body size plus range by date for cladoceran and copepod zooplankters in Sea Lion Cove Lake, 1982.

Taxa and length statistics (mm)	3/17	5/18	6/3	6/16	Sampling date 7/7	7/20	8/3	9/2	10/7	10/14	11/9	Total range and seasonal weighted mean
CLADOCERA												
Bosmina sp.												
range	0.38–	0.38–	0.32–	0.33–	0.34–	0.32–	0.33–	0.35–	0.35–	0.39	0	0.32–
	0.48	0.60	0.69	0.74	0.62	0.53	0.75	0.56	0.54	0.55		0.75
mean	0.42	0.54	0.49	0.49	0.44	0.43	0.45	0.46	0.48	0.49	0	0.43
std. dev.	0.04	0.05	0.11	0.12	0.07	0.06	0.12	0.05	0.05	0.03	0	––
Holopedium gibberum												
range	0	0	0	0	0	1.54–*	0.98–*	0	0	0	0	0.98–
						1.60	1.20					1.60
mean	0	0	0	0	0	1.57	1.09	0	0	0	0	1.33
std. dev.	0	0	0	0	0	0.04	0.16	0	0	0	0	––
COPEPODA												
Diaptomus sp.												
range	0.62–	0.72–	1.12–	0.93–	1.57–	1.48–	1.53–	0	0	0	0	0.62–
	1.19	2.08	2.15	1.76	2.10	2.15	2.15					2.15
mean	0.94	1.14	1.53	1.57	1.81	1.91	1.93	0	0	0	0	1.54
std. dev.	0.16	0.33	0.24	0.22	0.19	0.19	0.17	0	0	0	0	––
Epischura sp.												
range	0	0	0	0	1.72–	1.19–	0.81–	0.91–	1.09–	1.14–	1.08–	0.81–
	0	0	0	0	1.98	1.97	1.90	1.52	1.30	1.24	1.22	1.98
mean	0	0	0	0	1.85	1.74	1.23	1.12	1.21	1.19	1.15	1.35
std. dev.	0	0	0	0	0.10	0.22	0.41	0.15	0.05	0.03	0.04	––
Subtotal (Calanoid)												
range	0.62–	0.72–	1.12–	0.93–	1.57–	1.19–	0.81–	0.91–	1.09–	1.14–	1.08–	0.62–
	1.19	2.08	2.15	1.76	2.10	2.15	2.15	1.52	1.30	1.24	1.22	2.15
mean	0.94	1.14	1.53	1.57	1.82	1.82	1.51	1.12	1.21	1.19	1.15	1.46
std. dev.	0.16	0.33	0.24	0.22	0.17	0.22	0.48	0.15	0.05	0.03	0.04	––
Cyclopoid copepods												
range	0.56–	0.68–	0.41–	0.54–	0.55–	0.48–	0.55–	0.36–	0.44–	0.43–	0.47–	0.36–
	0.63	0.85	0.96	0.93	0.84	0.90	0.78	0.83	0.71	0.83	0.74	0.96
mean	0.59	0.78	0.75	0.75	0.67	0.69	0.67	0.52	0.53	0.59	0.55	0.61
std. dev.	0.02	0.06	0.13	0.12	0.08	0.09	0.08	0.13	0.07	0.12	0.06	––

* Only two organisms in sample.

During 1982 the calanoids remained the largest individual zooplankters; lengths ranged from 0.62 to 2.15 mm (Table 11). Mean body sizes ranged from 0.94 to 1.82 mm; the weighted mean seasonal body size was 1.46 mm. Further, the body sizes of both *Bosmina* and *Cyclops* remained less than one-half that of the calanoid zooplankters. For example, *Bosmina* ranged in body size from 0.32 to 0.75 mm; mean sizes, from 0.42 to 0.54 mm. The overall *Bosmina* body size in 1982 was considerably less than that observed in 1981; i.e., 0.43 versus 0.51 mm, respectively. In contrast, individual body sizes of *Cyclops* ranged from 0.41 to 0.96 mm; sample means ranged from 0.52 to 0.75 mm. Overall, *Cyclops* mean body size in 1982 was very similar to that observed in 1981; i.e., 0.61 versus 0.65 mm, respectively. Finally, in respect to differences in body size between *Diaptomus* and *Epischura*, we observed that, in terms of seasonal-mean body size and larger individuals, *Diaptomus* exceeded *Epischura*; however, *Diaptomus* exhibited the widest range in sizes since the smaller individuals recorded were also diaptomids.

DISCUSSION

Within the three years of this prefertilization study, we have defined both the preexisting limnological state of Sea Lion Cove Lake and the capacity of the lake to accept additional loading of nitrogen and/or phosphorus.

Sea Lion Cove is a shallow, dimictic system that forms a stable thermal structure in early June, which persists until the end of September. Thus, an epilimnion exists within the lake for approximately 14-16 weeks; during that time, surface temperatures reach 14°C and even exceed 16°C for short periods of time. However, the interesting feature of the lake is that the light compensation point lies deeper than the thermocline or metalimnion (Figure 8). In each of the 3 years of study, the euphotic zone
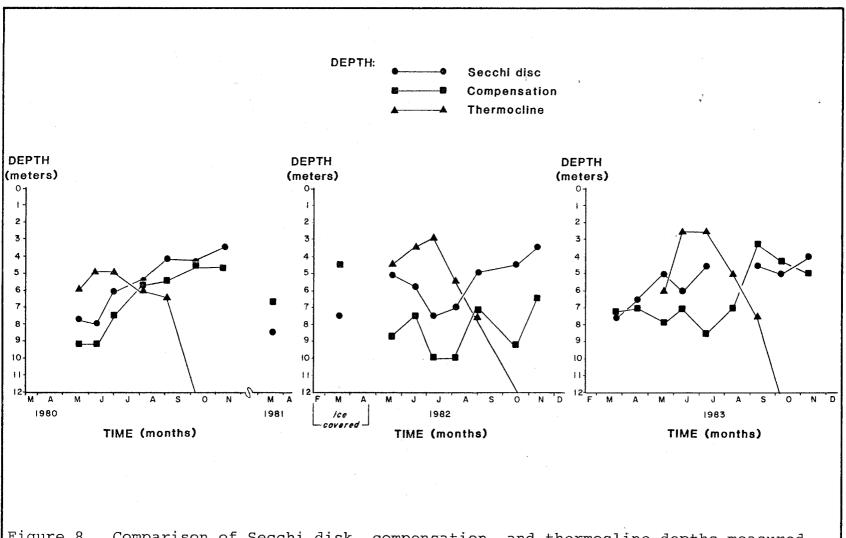
Figure 8. Comparison of Secchi disk, compensation, and thermocline depths measured at the mid-lake sampling station on Sea Lion Cove Lake, 1980-81, 1982, and 1983. Depth of the compensation point delineates the euphotic zone while the depth of the thermocline determines the lower extent of the epilimnion.

has exceeded the depth of the epilimnion from May through August. Thus, the extent of the trophogenic zone within the limnetic portion of the lake has not been confined to the epilimnion but has encompassed a considerable portion of the hypolimnion. This feature adds to the potential of the lake to increase annual primary production, since nutrient shortages within the epilimnion need not limit the production of specific species of phytoplankton (Kiefer et al. 1972). In addition, the warming of the hypolimnion that is attributable to the extended turnover period in the spring and, perhaps, to direct solar heating (Yan 1983) also increases the potential of hypolimnetic strata to add to the productive base of the lake. Not only do the warmer temperatures increase biological activity and, thus, primary production, but they also hasten decomposition reactions and subsequent mineralization of algal nutrients. Finally, the vertical differences occurring in light regimes, temperature profiles, nutrient concentrations, and nutrient ratios allow a clear segregation of the lake into differing habitats that are occupied by separate populations of phytoplankton

Pursuant to the concept that a sizeable contribution of annual primary production is provided by deep layers of phytoplankton, we found that in 1983 surface chl a equalled 0.77 ppb within the epilimnion, but during the same interval, it equalled 1.19 ppb at the compensation point, which was well within the hypolimnion. However, even though chl a levels (standing crop) were relatively high within the hypolimnion, the actual rate of production may have been low. Evidence of productivity differences between the two layers may be seen in the inorganic nutrient profiles. For example, because of a higher potential rate of production per unit chl a within the epilimnion, the inorganic nitrogen concentrations within these strata were reduced from 20 during May to undetectable levels by the first week of July. In contrast, inorganic nitrogen levels within the hypolimnion remained between 20 and 40 ppb; i.e., demand for inorganic nitrogen within the hypolimnion did not exceed its supply. However, since deep-water populations of phytoplankton are relatively immune from surface-related washout

associated with fast-flushing systems like Sea Lion Cove, long-term contributions to the annual production within the lake by deep-lying phytoplankton may be significant.

We found that nutrient levels and the atom ratios of inorganic nitrogen to total phosphorus remained at reasonable levels well into June and as late as the first part of July. At the same time (except for 1982), chl a levels during the early portion of the year were relatively robust. As a consequence, small herbivorous zooplankters (rotifers) bloomed in June and into July and were replaced by the larger filter-feeding *Bosmina* as the season progressed. Further, it appears that both the numerical density and the duration of the rotifer population increase in the spring curtail subsequent *Bosmina* abundance in the fall.

Even though *Bosmina* were the most numerous of the macro-zooplankton, calanoid zooplankters are of particular importance because of their active selection by foraging coho fry (*see* Part I of this report). The calanoid zooplankton community within Sea Lion Cove Lake consists of two species: the earlier-timed *Diaptomus* and the seasonally delayed *Epischura* (Figure 9). Calanoids appear to be selected by rearing coho fry because of a large body size not exhibited by the more numerous *Cyclops* and *Bosmina*. Indeed, the entire Sea Lion Cove zooplankton community, regardless of species, has large body sizes, especially when compared to those of the Falls Lake sockeye salmon rearing system (Koenings et al. 1984).

Since dominance by larger zooplankters is commonly found when vertebrate predation pressure is low (Patalas and Salki 1984), the finding of zooplankters in fishless Sea Lion Cove Lake that had larger body sizes than in Falls Lake was not unexpected. Considering this, the effect on the zooplankters to a coho fry introduction on 8 July 1982 was apparently low because seasonal densities and individual body sizes were not drastically altered, when compared to equivalent data obtained in 1980 and 1981.
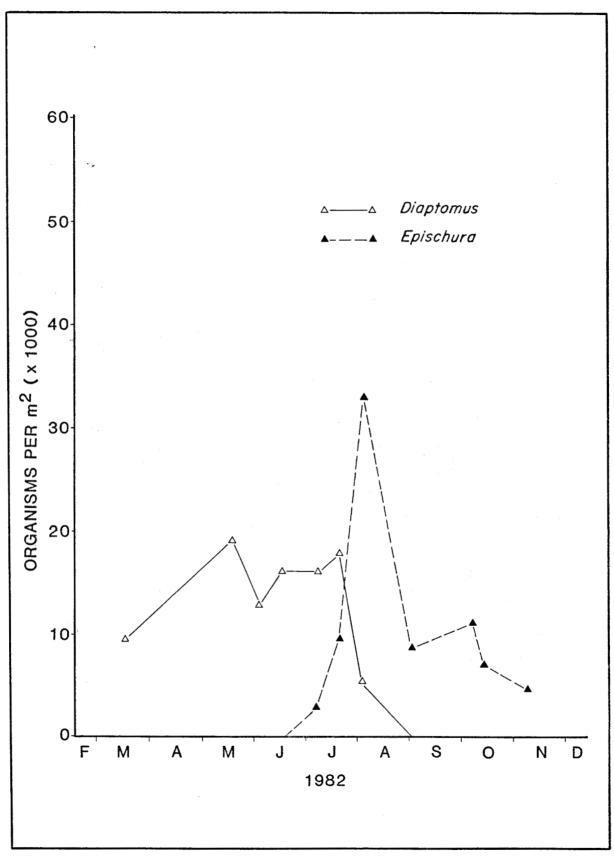
Figure 9.   Seasonal variation in the densities of *Diaptomus* and *Epischura* in Sea Lion Cove Lake, 1982.

However, relative to the location of the open-water strata used to collect zooplankton, the lack of a distinct change in the zooplankton community may have resulted from coho fry feeding behavior. That is, if coho fry pressured the littoral area of the lake to a more consistent degree than that of the open-water areas, littoral zooplankters may reflect the predation pressure more than the limnetically sampled populations. A similar, but reversed, relationship between a fish predator and zooplankter prey was established by Brooks and Dodson (1965) in Crystal Lake. Large forms of zooplankter were found only in the littoral zone and near the sediments, because the fish predator *Alosa* fed exclusively in the pelagic zone. Finally, another consideration is the conspicuous feature of limnetic cladoceran and copepod behavior that exhibited a distinct avoidance of the littoral zone. Moreover, Wetzel (1975) states that there is a direct relationship between the elevation of the horizon (as in mountain lakes) and the width of the nearshore zone that contains reduced concentrations of pelagic zooplankton (higher=wider).

Nonetheless, calanoid zooplankters are important to the growth of coho fry. As such, the calanoids are the target species for enhancement efforts aimed at increasing the rearing capacity of Sea Lion Cove Lake. Previous work at Bear Lake, Alaska (Kyle and Koenings 1983) revealed that initiation of nitrogen additions increased population densities of such cladocerans as *Bosmina* within the same season. However, the response of *Diaptomus pribliofensis* was delayed for an additional year. Thus, to enhance populations of the parthenogenic-reproducing cladocerans, nutrient additions need take place only within the target season. In contrast, to enhance populations of the sexually reproducing calanoid zooplankters, nutrient additions need to precede and be concurrent with the target year. As additional coho fry plants are planned for Sea Lion Cove in the spring of 1985, enrichment of the lake should take place in 1984 in order for larger calanoid densities to be in place by 1985.

Seasonal abundance patterns of individual zooplankters are driven
by unique combinations of light, temperature, nutrients, algal
density (segregated between several species), predation, and
competition, to mention a few. As such, environmental conditions
in Sea Lion Cove may provide insight into the causes of the
differential population densities of zooplankters that were
observed in 1980 and 1982. That is, in 1982 mean population
densities of calanoid zooplankters were high, relative to those in
1980; whereas, those of the usually dominant *Bosmina* reached
seasonally mean levels of only one-third those found in 1980. In
addition, rotifer levels in 1982 were slightly elevated, relative
to those observed in 1980.

As the smaller species of filter-feeding zooplankters (i.e.,
Bosmina and the rotifers) substantially overlap in food-size
preference, large spring densities of the more rapidly reproducing
rotifers could reduce the number of immature *Bosmina* that subse-
quently mature and reach the breeding pool. This would reduce the
eventual peak density of adult *Bosmina* that are usually found to
occur during the fall period. In turn, as *Bosmina* are capable of
rapid population increases (asexual reproduction) following a
pulse in food supply, they (like the rotifers) are characterized
as an opportunistic species. In contrast, calanoid copepods are
not as opportunistic because their sexual reproduction does not
allow rapid increases in population density. To compensate for
the advantage imparted by the cladoceran reproductive strategy,
calanoids require a large body size in order to both compete with
the cladocerans as filter feeders and to produce larger clutch
sizes of young. In addition, the larger body size enables
calanoids to be able to choose larger-sized food particles (by
raptorial feeding) than can be handled by the obligate filter-
feeding bosminids (Burns 1968). Overall, because of the compet-
itive pressure from specialized filter feeders, calanoids require
a large body size and, consequently, a better ability to escape
predators and effectively survive as a population.

The competitive advantage of *Bosmina* can be further reduced by a lack of a highly pulsed food supply and by low food densities. That is, an increased food supply, pulsating between high and low cycles, favors the quickly reproducing and fast-growing cladocerans and rotifers. Thus, deep-water, cold, unproductive lakes that·consistently have deep-light penetration profiles, high N:P ratios, and low chl a levels also have robust populations of copepods. The inference is that these features confer an increased competitive advantage to copepods over the cladocerans by providing environmental conditions ideal for copepod reproduction; i.e., a continual low level of forage.

During spring, daylight hours, nutrient levels, and nutrient atom ratios (N:P) are high, relative to the summer period; the result is the phytoplankton "bloom". This bloom consists of a large number of small-sized species of algae preferred by cladocerans (Porter 1977). Given the increasing temperatures, rotifers and *Bosmina* quickly bloom following the rapid algal increase. At these relatively higher densities of food, competition is lessened, and weakly competitive species (like *Diaptomus*) can coexist with the more dominant species (rotifers and *Bosmina*), especially if food preferences are slightly different. When food densities or algal quality decreases, competition becomes much more intense; closely aligned groups (e.g., rotifers and *Bosmina*) are especially affected. At this time, however, the specialized ability of the calanoids to utilize larger forms of algae may relieve the competitive pressure and allow calanoid density increases after the population downturn of the other generalized filter feeders (Richman and Dodson 1983). Another feature of importance is that the absolute amount of growth achieved by calanoids during the development from nauplii to adults is inversely related to temperature and directly related to food supply.

When the above generalizations to conditions actually observed in Sea Lion Cove during 1980 and 1982 were applied, we found that

1980 produced robust levels of phytoplankton that pulsed upward in the fall; this condition was followed by a major peak in the density of *Bosmina*. In addition, the weakly feeding cladoceran, *Holopedium*, was found throughout the summer season, but in contrast, calanoid densities were low. In 1982 phytoplankton levels were not only pauperate to nonexistant but were only weakly pulsed in the fall.

Consequently, *Bosmina* densities were one-third of those found in 1980, and *Holopedium* disappeared completely from the zooplankton community. However, the densities of both calanoids increased, particularly those of *Epsichura* (the fall calanoid), which in 1980 faced intense competition from *Bosmina*. Thus, in 1980 when the lake remained open throughout winter and lake temperatures were relatively high from top to bottom, *Bosmina* densities soared; and calanoid densities sagged in the face of mild temperatures and a robust food supply, both of which favor the cladoceran reproductive strategy. However, in 1982 the lake was ice covered, water temperatures were reduced to <2°C from top to bottom, and the phytoplankton pulse following breakup was nonexistent. Both features do not favor the development of cladocerans; i.e., *Holopedium* disappeared entirely from the zooplankton community and *Bosmina* densities reached all-time lows. Consequently, driven by the lack of cladocerans, calanoid densities expanded, particularly those of the late-arriving *Epischura*.

Cumulatively, inlake conditions that especially favor bosminid (or rotifer) reproduction are not conducive to the production of calanoids. Producing an increase in zooplankter food supply without unduely favoring cladocerans or rotifers may be achieved by applying a low level (below critical loading) of a high N:P atom ratio fertilizer in a continuous nonpulsed fashion. This would minimize the formation of a high/low cycled food supply that favors cladoceran reproductive strategy over that of the calanoids. The desire at Sea Lion Cove is to emphasize the production of calanoid zooplankters, because high growth rates of

stocked coho fry have been shown to be correlated to the existence
of these large calanoids. That is, a relation has been shown to
exist between size selection of prey and foraging efficiency.
Thus, coho fry growth rates were significantly higher in the
presence of a larger-body-sized prey, and much of this differen-
tial growth can be attributed to the efficiency of foraging; i.e.,
the expenditure of energy, or metabolic cost, in obtaining food
relative to the return.

Sea Lion Cove Lake Nutrient Loading

The present loading for phosphorus is estimated to be 96 mg
p/m^2/yr, with a critical loading level of 285 mg P/m^2/yr
(Vollenweider 1976). Thus, Sea Lion Cove Lake is currently at 37%
of critical loading. We plan to increase the loading rate an
additional 40% to give an overall loading of 77% of critical. Our
target loading is thus defined as 200 mg P/m^2/yr, which leaves 104
mg P/m^2/yr to be provided by the addition of fertilizer. The
amount of fertilizer necessary to provide an additional 104 mg
P/m^2/yr is 190 liters (50 gal) of 27-7-0 at 0.16 kg of phos-
phorus/gal.

The fertilizer to be used should have a high atom ratio of N:P
(>18:1), given the depletion of inorganic nitrogen already noted
to occur within the epilimnion of the lake. Initially, a liquid
product (27-7-0) will be dripped continually at a constant rate
into the lake from several rafts permanently moored in the lake.
Because of the density of the initial product, a 50:50 v/v
dilution with surface water is required before application to the
lake surface. Finally, because of our concern over the lower
IN:TP ratios during the late-June to early August period, it may
be prudent to augment the additions of the 27-7-0 (N-P$_2$O$_5$-K) with
a 32-0-0 product.

An alternative strategy currently under consideration is to
broadcast a slow-leaching solid product over the 2-m-deep shelf

surrounding Sea Lion Cove Lake two times a year (May and again in August); this would provide continuous fertilization of the system during the summer period.

Recommendations

1. Apply inorganic fertilizer (using a high N:P atom ratio of 18:1) at a continuous rate that will result in an increase in the phosphorus loading from 37% to 77% of critical.

2. Fertilizer addition should begin no earlier than the later part of May and last until the first part of October.

3. Continue to monitor the inorganic nitrogen levels in order to prevent a further lowering of the inorganic nitrogen to total-P ratio and to determine the effectiveness of fertilization in achieving an increase in the density and body size of calanoid zooplankters.

4. Investigate the use of a solid, slow-leaching fertilizer that will provide a continuous source of nutrients to the epilimnion of the lake, given a twice a year application program.

5. If success is achieved in raising the density of large-body-sized zooplankters, investigate the possibilities of stocking coho fry at a greater density than in 1982 or of stocking fry yearly, instead of employing an alternating stock/fallow cycle.

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